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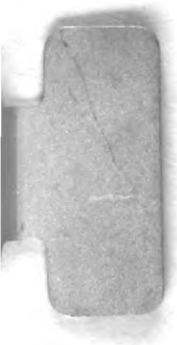

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TRANSACTIONS
OF THE
AMERICAN GEOPHYSICAL UNION

Volume 8

1927

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BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

July 1927 **Number 61**

TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION
EIGHTH ANNUAL MEETING, APRIL 28 AND 29, 1927
WASHINGTON, D. C.

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
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BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

July 1927 Number 61

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INTRODUCTION

The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union, and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The object of the Union is to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of this object, the Union is divided into six sections in accordance with the organization of the International Geodetic and Geophysical Union as follows: (*a*) Geodesy; (*b*) Seismology; (*c*) Meteorology; (*d*) Terrestrial Magnetism and Electricity; (*e*) Oceanography; (*f*) Volcanology.

Annual assemblies of the Union and annual meetings of its sections for the discussion of reports and symposia are held each year. Thus far there have been eight such assemblies and meetings, all held in Washington, D. C. The transactions of these annual assemblies and meetings have been published as bulletins of the National Research Council as follows: Second, 1921, Bulletin No. 17; fourth, 1923, Bulletin No. 41; sixth, 1925, Bulletin No. 53; seventh, 1926, Bulletin No. 56; and eighth, 1927, the present volume. The transactions of the first, third, and fifth annual meetings in 1920, 1922, and 1924, respectively, were devoted to discussion, there being no scientific papers presented, and, therefore, these transactions have not been printed and were mimeographed for limited distribution only.

The eighth annual assembly of the Union and the meetings of its sections were held April 28 and 29, 1927, in the building of the National Academy of Sciences and National Research Council at Washington, D. C. The assembly took place on the afternoon of April 29 and the meetings of sections on the morning and afternoon of April 28 and on the morning of April 29. The meetings were devoted chiefly to symposia and discussions on selected topics relating to current problems and developments in geophysics. An exhibit of geophysical instruments, researches, and applications was prepared and displayed during April 22 to April 29, 1927 (except Sunday, April 24), in the exhibit rooms of the Academy-Council building. Thanks to the efforts of the several institutions and individuals taking part, the exhibit proved of great interest.

The Union was favored by the attendance of an unusual number of visitors representing the National Committee of Canada and various Canadian governmental departments and universities, thus evidencing an active spirit of cooperation on the part of the two countries. Those

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in attendance from Canada were: A. Amos, Director of the Hydraulic Section of the Department of Lands and Forests of the Province of Quebec; A. S. Eve, Director of Physics, McGill University; Ernest A. Hodgson, Seismologist of the Dominion Observatory; A. G. Huntsman, Director of Atlantic Stations of the Biological Board of Canada; Noel J. Ogilvie, Director of the Geodetic Survey of Canada; John Patterson, Assistant Director, Canadian Meteorological Office, and Charles Savary, Chief of the Section of Geodesy and Cartography of the Department of Lands and Forests of the Province of Quebec. It will be noted that a number of these representatives also presented papers before the meetings.

In addition to the attendance of a majority of the members of the Union from all parts of the United States, the following guests and delegates representing various institutions and universities in the United States were present: W. S. Adams, Director, Mt. Wilson Observatory; Joseph G. Brown, Professor of Physics, Leland Stanford University; Perry Byerly, Seismologist, University of California; C. A. Heiland, Head of the Department of Geophysics and delegate from the Colorado School of Mines; J. S. Joliet, S. J., of the St. Louis University; L. A. Jones, Physicist of the Research Laboratory of the Eastman Kodak Company; E. H. Kincaid, Lieutenant, U. S. N., Hydrographic Office; G. W. Pickard, Consulting Engineer of the Wireless Specialty Apparatus Company; W. C. Repetti, S. J., of the St. Louis University; Parker D. Trask, Research Associate of the American Petroleum Institute, and George Winchester, Professor of Physics, Rutgers College and the State University of New Jersey. Authors other than members of the Union who presented or contributed papers at the meetings included: O. S. Adams, Coast and Geodetic Survey; L. B. Aldrich, Astrophysical Observatory; E. T. Allen, Geophysical Laboratory; H. C. Avers, Coast and Geodetic Survey; Gregory Breit, Department of Terrestrial Magnetism; J. P. Buwalda, California Institute of Technology; I. F. Hand, U. S. Weather Bureau; C. V. Hodgson, Coast and Geodetic Survey; Paul Kirkpatrick, University of Hawaii; F. B. Littell, Naval Observatory; W. C. Mendenhall, Geological Survey; J. T. Pardee, Geological Survey; T. Parkinson, Bureau of Standards; Edison Pettit, Mt. Wilson Observatory; E. S. Shepherd, Geophysical Laboratory; Philip S. Smith, Geological Survey; C. A. Swick, Coast and Geodetic Survey, and E. G. Zies, Geophysical Laboratory.

The success of the meetings was largely due to the active interest of the delegates, guests, and authors of papers presented, and this opportunity is taken on behalf of the Executive Committee of the Union to express most grateful appreciation to them.

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RESOLUTIONS

RESOLUTION ON TRANSLATIONS OF REPORTS ON SEISMOLOGICAL INVESTIGATIONS PUBLISHED IN THE JAPANESE LANGUAGE

(Submitted by Section of Seismology and adopted at general assembly of the Union, April 29, 1927)

Whereas, it has become known that the reports of much of the seismological investigations carried on in Japan will hereafter be published in the Japanese language only, and

Whereas, This procedure is calculated to deprive most of the American students in this field of research of the advantages of this literature, be it

Resolved, That this matter be brought to the attention of the National Research Council in the hope that the Council may provide that this literature be rendered into English, also that provision be made whereby mimeographed copies of these translations be supplied investigators at research institutions gratis and to business concerns, insurance companies, and others interested at cost, and

Resolved, further, That, should such an arrangement be feasible, a committee of the American Geophysical Union be empowered to make a choice of the material to be so translated and distributed.

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REPORTS AND PAPERS

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GENERAL MEETING

(Washington, D. C., April 29, 1927)

REPORT OF THE DELEGATES OF THE AMERICAN GEOPHYSICAL UNION TO THE THIRD PAN-PACIFIC SCIENCE CONGRESS AT TOKYO, JAPAN, IN OCTOBER, 1926

(Delegates—Arthur L. Day, N. H. Heck, T. A. Jaggar, G. W. Littlehales, George F. McEwen, H. F. Reid, T. Wayland Vaughan, Bailey Willis)

The interest of the American Geophysical Union in the Third Pan-Pacific Science Congress held at Tokyo, Japan, in October, 1926, lies in the fact that the Division of Physical Sciences of the National Research Council included in its scope all the subjects of geophysics into which the work of the American Geophysical Union is divided. Furthermore, in establishing the Pacific Science Association as a permanent organization, the plan was adopted of having each country represented by a National Committee, in the case of the United States, the National Research Council. Inasmuch as the function of the American Geophysical Union is to keep the National Research Council informed of the activities coming within its field, there is an opportunity for service in this connection.

Abstracts of all papers were printed in advance of the meetings, but the complete papers are not yet available. All that can be done at present is to give a broad picture of the activities in regard to the six subjects represented by the sections of the American Geophysical Union.

OCEANOGRAPHY

This subject will be reported in considerable detail by Dr. T. Wayland Vaughan to the National Research Council and those interested may consult his report. The activities in oceanography were well organized as there was in existence a Committee on the Physical and Chemical Oceanography of the Pacific. This, in addition to its interim activities, provided a basis for informal action before and during the meetings and proved helpful by promoting informal discussion and preparing resolutions and recommendations.

About forty papers were presented on subjects directly relating to oceanography and there were others bearing on oceanographic problems. At least ten countries were represented. Both the physical and biological divisions of oceanography were discussed. The subjects relating to

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geophysics included: Oceanic circulation; mean sea-level; bottom configuration as obtained both by direct measurement and by acoustic methods; correct velocities for acoustic soundings; relations of seismology to oceanography; marine meteorology; proposed expeditions including that of the *Carnegie* and other related subjects.

In the case of oceanography, resolutions proposed by the Division of Physical Sciences and approved by the Congress covered a wide range. One of the most important was that calling for the formation of a Committee on Oceanography for the Pacific, replacing the committee which has been mentioned and broadening its scope. It is contemplated that the work of this Committee will eventually result in the formation of an international council for the exploration of the sea for the Pacific similar to that now in existence for the Atlantic. The president of the Congress appointed Dr. T. Wayland Vaughan as chairman of this committee. Other resolutions dealt with the organization of the committee and provided for subcommittees on special subjects.

Another resolution called for closer cooperation between the National Committees and between members of subcommittees and suggested the submission of programs and seeking of suggestion and advice in order to secure standardization and coordination, and provided for reports to the International Chairman to be submitted by him at future meetings.

Other resolutions related to obtaining more numerous and more accurate surface-temperature readings and called attention to the need for their publication; to the daily charting of the meteorology of the world; to the study of coral reefs, and to the need for complete determination of the bottom configuration, especially in the vicinity of islands.

The work of the Dutch Geodetic Commission through Dr. J. Vening Meinesz in making gravity-determinations at sea by means of a submarine was strongly endorsed, and the hope expressed that other nations would take up and extend this work.

A number of the delegates visited the Marine Biological station at Misaki, Sagami Bay, and the Hydrographic Office at Tokyo, thereby becoming familiar with some of the oceanographic work of Japan.

SEISMOLOGY

Naturally this subject received considerable attention, three meetings being given to various phases of the subject and ample opportunity being given to visit the seismological installations in the vicinity of Tokyo and elsewhere.

The meeting of the Section of Seismology included two symposia, one on the network of earthquake observations of the Pacific, the other on

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the transmission of earthquake waves in the Pacific region. Representatives from three countries discussed these subjects. Other papers described a long-period pendulum now in use in Japan and another the relation to the focus of the point of beginning of the long waves. One paper dealt with the correlation between earthquake-frequency and earth-tides and another on variation of latitude, tide, and earthquakes. That biology can not be eliminated from earthquake study was shown in the paper on the effect of the Kwanto earthquake on marine organisms.

The subject of tectonics, especially crustal movements connected with earthquakes, was discussed in connection with matters relating to geodesy and one meeting was given to the principles of earthquake-proof construction of buildings, involving, of course, the motions which have to be resisted. No resolutions were presented from this section, not so much on account of lack of need for international cooperation, but for the reason that there has been no machinery to provide for such co-ordination. A resolution originating in this section provided for interim committees for those sections which desired them, to deal with matters relating to the subject between meetings and serve as an informal means of preparing resolutions and recommendations at the meetings. It is hardly to be expected that progress will be made without such organization and it is hoped that the new plan will prove useful at the meeting in Java.

A number of the delegates were able to visit some of the institutions where seismological observations are made though the time available was totally inadequate. The Seismological Institute of the Imperial University of Tokyo has a very elaborate collection of instruments from the earliest to the more modern. The Central Meteorological Observatory at Tokyo also operates a number of seismographs including Japanese and European designs. Special instruments have also been developed at Kyoto and Kyushu universities.

It is of special interest to note that as a result of the great earthquake all the older instruments are being replaced with newer types having electro-magnetic damping. The extent of this undertaking is evident when it is realized that every institution in Japan which is capable of carrying on the work is operating seismographs.

It was learned that although there is considerable publication in English, much valuable work has never been translated; and it appears that it is a proper task for the Geophysical Union to find a means of translating the more essential parts of the available material.

The amount of work being done in Japan is so great and the problem so complicated that it is difficult to determine what progress has been made.

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GEODESY

This subject was treated in connection with tectonics. There was a general presentation of the geodetic and geophysical problems of the Pacific. The need for gravity-observations at sea was emphasized and there was some discussion of isostasy. However, the chief subject on which geodesy has a bearing was the discussion of crustal movement especially in Japan. It will be noted that under the discussion of oceanography the extension of gravity-observations at sea was urged.

TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

Representatives of three countries discussed recent contribution to the knowledge of terrestrial magnetism in the Pacific. One paper gave the results of a study of the magnetism of volcanic rocks. The ocean work of the *Carnegie* was described with special reference to the work in atmospheric electricity. Atmospheric-electric observations in the Dutch East Indies were described.

A number of the delegates visited the Kakioka Magnetic Observatory, about seventy miles northwest of Tokyo. This is now being modernized, all of the buildings are being replaced and entirely new instrumental equipment is being installed. Atmospheric potential-gradient observations are being made. Special apparatus for the study of abrupt beginning of magnetic storms is in use.

METEOROLOGY

There was a symposium on typhoons with discussion of the subject as based on very complete studies in the Philippine Islands, China, and Japan. It was brought out that the great number of observing stations is making it possible to follow and study a typhoon from its inception till it disappears.

Upper-air observations from airplanes with some of the difficulties involved were discussed. Weather types of China and the Netherlands East Indies were treated. The distribution of accidents due to lightning in Japan was discussed, interesting statistics being given.

In addition to visits by most of the delegates to the Central Meteorological Observatory at Tokyo, a group visited an aerological station and one of the mountain weather-stations.

This is scarcely the place to discuss the hospitality and the elaborate social entertainment. It is important, however, that record should be made of the many courtesies extended. Great care had to be taken to

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express only reasonable wishes as they were certain to be gratified. Our questions were answered in detail, and every effort was made to explain to us, where necessary, the various things that we saw. Many of the delegates left Japan feeling regret that the time was so short that they could not do more than obtain a broad picture of what is going on in science. This is particularly the case in seismology, a subject of great practical importance in that country.

The contacts made with scientists from all parts of the Pacific are of value not only to the delegates but they are an asset to the Union in carrying on its work. It is important that the American Geophysical Union as it more and more adequately fulfills its functions should not overlook the importance of keeping in close touch with the rapidly growing scientific effort in the Pacific region.

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SYMPOSIUM ON SOME FACTORS OF CLIMATIC CONTROL

INTRODUCTORY REMARKS

W. J. HUMPHREYS

Numerous factors enter into the problem of the control of climate, and climate is subject to change. The geologists tells us that we have had many variations of climate in the past, and we know that we have many varieties, sometimes even in the same locality, in New England, for instance. What are the things that determine the climate for a particular place? The radiation from the Sun, the composition of the atmosphere that permits certain radiations to get through and shuts others out, the way the wind blows, the way the water flows, the heights of mountains and their locations in respect to the oceans and directions of prevailing winds, and a host of other influences. If we pulled down mountains, the climate of that region would be modified. If we erected high mountains, the climate in that section would be greatly changed, made more rainy on the windward side and drier to the leeward. Great quantities of fine dust in the upper air would make our climate colder. A variety of things may be factors, and they have not always been the same—constant or of equal importance. There was a time when there was free circulation from the Gulf of Mexico to the Arctic Ocean, and from the Persian Gulf and Caspian Sea also to the Arctic Ocean. Another factor is the nature of the covering of the Earth; if it were covered with white sand, the climate would be different than if covered with black soil. The white sand would reflect much insolation which the black soil would absorb. Again, there appears to be a critical extent for polar ice-caps such that a comparatively slight change in this extent, either increase or decrease, would lead automatically to a much greater change in the same direction. The combination of such factors obviously would produce effects which separately they would not. Many of these factors could be discussed here to good advantage, especially all those considered by C. E. P. Brooks in his "Climate Through the Ages." Obviously though, it is quite impossible to cover the whole of this subject in the short time available, so that we have arranged for papers on only the more important factors.

U. S. Weather Bureau,
Washington, D. C.

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THE INFLUENCE OF THE ATMOSPHERIC CONSTITUENTS UPON CLIMATE

L. B. ALDRICH

Climate is largely determined by the prevailing range of temperature. The temperature is maintained first, by the solar radiation which continuously falls upon our atmosphere at the mean rate of 1.93 calories per square centimeter per minute; and secondly, by the exceedingly complicated series of absorptions, scatterings, reflections, endless re-radiations, and convection- and conduction-effects which result from the passage of the solar beam through the atmosphere. Langley,[1] and more recently Dietzius[2] and others, have shown that the Moon, receiving solar radiation per unit area identical with the Earth, experiences within the brief interval of a lunar eclipse a change of temperature ranging from about that of boiling water to far below freezing. On the Earth the average daily range is less than 10° C and seldom exceeds 20° C. The difference is due to this: the Earth has an atmosphere; the Moon has not. Oxygen and nitrogen, which comprise the bulk of the atmosphere, have relatively little effect on temperature. From other constituents, however, comprising less than three per cent of the weight of the atmosphere are highly important as affecting temperatures. These constituents are water (both as water vapor and in the form of clouds), dust, ozone, and carbon-dioxide.

What happens to the solar beam after it enters the atmosphere? On a clear day at sea-level, with the Sun in the zenith, about seventy-five per cent of the incident solar-radiation is transmitted directly to the Earth through the atmosphere. The remainder is partly scattered and reaches the Earth in the form of sky-light, partly selectively absorbed, in the main by water vapor, and partly reflected out to space. For other altitudes of the Sun, as the air-path increases the amount directly transmitted decreases and the sky-brightness increases. On hazy days, due to a larger content of water vapor or fine dust or both, less radiation is directly transmitted and more is scattered, absorbed and reflected. To illustrate the variation in intensity of the directly transmitted beam even in a cloudless sky and at an altitude of 3,000 meters above sea-level, I have chosen more or less at random the following observations on four different days at the Montezuma station of the Smithsonian Institution.

The last column is a measure of the amount of scatter due both to dust and water-vapor haze. The first two days show that an increase of

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[1] Mem. Nat. Acad. Sci., Vol. 4, 9th Mem.: 193 (1890).

[2] Akad. Wiss. Wien, Ber., (2A), 132: 5-6, 193 (1924).

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Date	Calories directly transmitted (per cm² per minute, at air mass 1.5 and mean solar-distance)	Precipitable water (determined spectroscopically)	Brightness of sky in a concentric ring 30° diameter around the Sun (in calories per cm² per minute)
Aug. 6, 1920.....	1.632	.074 cm	.0100
Aug. 10, 1920.....	1.527	.916 cm	.0100
Aug. 21, 1924.....	1.468	.260 cm	.0208
June 22, 1924.....	1.579	.310 cm	.0103

water-vapor content depleted the solar beam seven per cent. The last two show that though the water-vapor content remained unchanged, an increase of dust sufficient to double the diffuse scatter also produced a seven per cent depletion. And comparing the first and third days, an eleven per cent depletion is found in a hazy, moderately wet sky as compared with a dry, clear sky. On cloudy days practically no radiation is directly transmitted and more than seventy-five per cent is reflected back to space from the upper surface of the cloud.[3]

The temperature at the surface of the Earth results from the balance between the incoming solar-radiation and the outgoing terrestrial-radiation. The albedo of the Earth is estimated to be forty-three per cent.[3] This leaves fifty-seven per cent available to warm the Earth. To maintain its mean temperature unchanged, the Earth must radiate to space as much as it receives. With a mean solar-constant of 1.93 calories, we have $1.93 \times .57 \times \frac{1}{4} = .28$ calories per cm² per minute being radiated to space by the planet Earth. Abbot[4] has shown that less than one-fourth of this is radiated by the Earth directly to space. The atmosphere is the principal source of the outgoing radiation—largely because of the absorptive power of water vapor and clouds, assisted in smaller degree by carbon-dioxide, ozone, etc.

The incoming solar-radiation lies almost wholly within the wave-lengths 0.3 μ to 3.0 μ with a sharp maximum at 0.47 μ. The outgoing terrestrial-radiation, since it comes from a far cooler source, lies almost wholly within the wave-lengths 4 μ to 50 μ with a maximum at 9.5 μ. The selective absorption of water vapor for solar-radiation occurs largely in a number of bands of wave-length greater than 0.8 μ. This is con-

[3] See Smithsonian Misc. Collect., 69, no. 10.

[4] Proc. Nat. Acad. Sci., 4: 104 (1918).

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siderably beyond the maximum of intensity. On a clear but humid day the absorption of solar radiation by water vapor would rarely be so great at fifteen per cent. In contrast, water vapor absorbs terrestrial radiation almost completely, except in the region around 10 μ, and even there it is partially absorbing. Fowle[5] computes that in an atmosphere containing one cm precipitable water, seventy-two per cent would be absorbed. This "greenhouse effect"—transmitting solar radiation but screening off the terrestrial—is still strong even in a very dry atmosphere. As Abbot shows, with so little as 0.003 cm of precipitable water, nearly fifty per cent of terrestrial radiation is absorbed. This fact—that even a very small amount of water vapor so strongly absorbs terrestrial radiation—makes it evident that reasonable variations in the water-vapor content of the atmosphere would have little effect on climate. One important factor, however, should be mentioned in this connection. At present on the average about fifty per cent of the Earth's surface is cloud covered. C. E. P. Brooks[6] has shown that, other conditions remaining the same, if the total amount of cloud were increased by one-tenth it would probably suffice to lower the mean temperature by 5° C, and vice versa. This does not seem surprising since the upper surface of a cloud reflects seventy-eight per cent of the incident solar-radiation, so that the quantity of heat available to warm the Earth is greatly decreased by an increase in total cloud-surface.

Dust particles suspended in the atmosphere have a quite different effect on temperature from that of water vapor. In 1913 Abbot and Fowle[7] published a paper on volcanoes and climate which showed that following the great eruption of Mt. Katmai in Alaska in June, 1912, the skies of Bassour, Algeria, and Mt. Wilson, California, were unusually hazy. Daily observations at both places disclosed that the atmospheric transmission-coefficients were reduced fully twenty per cent. This condition continued, though in less degree, during the summer of 1913. Abbot and Fowle also showed that similar hazy skies followed some of the great volcanic eruptions of former years. Humphreys[8] has made a careful study of the effects of fine dust in the upper air. He points out that dust particles absorb more of terrestrial than of solar radiation and this would tend to increase the Earth's temperature. He shows, however, that absorption is not the controlling factor and that scattering and reflection from dust particles produce the opposite effect. Dust

[5] *Ibid.*, p. 105.
[6] "Climate through the Ages," London, 1926, ch. 7.
[7] Smithsonian Misc. Collect., 60, no. 29.
[8] Physics of the Air, J. Franklin Inst., part 4, ch. 8 (1920).

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particles, being materially larger than air molecules, affect the long waves of terrestrial radiation in much the same way as air molecules act upon the shorter waves of solar radiation. That is, they merely scatter terrestrial radiation and reflect little. The solar radiation, however, is both scattered and reflected in large measure by the dust particles. On reasonable assumptions, Humphreys computes that the total effect of dust in preventing the transmission of solar radiation is thirty times as great as it is with terrestrial radiation. This he calls an "inverse greenhouse effect" which produces an eventual lowering of the surface-temperature. There is considerable evidence that lowered temperatures have followed volcanic eruptions. Brooks[9] computes that the twenty per cent reduction in the atmospheric transmission-coefficients such as occurred in the Katmai eruption of 1912, if long continued would lower the mean temperature of the earth over 5° C. On the other hand, he points out that the complete absence of volcanic dust would not raise the mean much over ½° C, an amount insufficient to account for the temperatures which prevailed during warm geological epochs.

Arrhenius,[10] in 1896, basing his computations on Langley's early work on the temperature of the Moon, estimated the effect of variations in the quantity of carbon dioxide in the atmosphere on the temperature of the Earth. He concluded that two and five-tenths to three times the present amount of CO_2 would increase arctic temperatures 8° or 9° C. If the CO_2 were decreased to 0.6 of its present value, he computes a lowering of temperatures in latitudes 40° to 50° of 4° or 5° C. Chamberlin[11] elaborated this theory in an effort to explain climatic variations during geological ages. Abbot and Fowle,[12] however, showed that as little as one-fortieth of the present amount of CO_2 exerted the maximum possible absorption-effect, and that in the two more important absorption bands of CO_2, at 4 to 5 μ and 14 to 15 μ, neither of which are in the region of maximum intensity of the terrestrial radiation energy-curve, water-vapor is nearly completely absorbing. Hence, even though the amount of carbon dioxide were to vary through a wide range the effect on the surface-temperature would be negligible. Humphreys[13] points out that a variation in CO_2 at levels above the water-vapor level, particularly a decrease, might alter temperatures, but that the total effect would be small.

The exact role of ozone in the atmosphere is still undetermined. The existence of ozone in the upper air has been shown by many observers.

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[9] Climate through the Ages, p. 134.
[10] Phil. Mag., London, 41: 237 (1896).
[11] J. Geol. 7: (1899).
[12] Ann. Astrophys. Obs. Smithsonian Inst., 4: 25.
[13] Physics of the Air, p. 567.

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And there is general agreement that the amount present is equivalent to about three mm of ozone at atmospheric pressure and that the total quantity is somewhat variable. A recent paper by Fabry[14] entitled "The Absorption of Radiation in the Upper Atmosphere" summarizes our present knowledge of the effect of ozone upon solar radiation. He shows that ozone must occur principally at very high altitudes. His theory as to its formation is as follows:

"Radiation of very short wave-length (λ less than 1850) acts upon oxygen transforming it into ozone; at the same time this radiation is strongly absorbed by the air. It is probable that such radiation exists in the solar emission; it must produce ozone in the Earth's atmosphere, but only in the highest part because it cannot reach the lower strata. Radiation of $\lambda = 1850$ is completely absorbed by ten meters of air at atmospheric pressure and could scarcely penetrate lower than the forty-km stratum. On the other hand, radiation lying between $\lambda = 2000$ and $\lambda = 3000$ decomposes ozone, and between these two inverse actions a state of equilibrium must be established, the quantity of ozone depending on the relative intensities of the two ranges of radiation." Assuming that the solar ultra-violet emission is identical with that of a black body at 6000° K, Fabry computes that ozone in the upper air obsorbs about four per cent of the incident radiation when the Sun is in the zenith. As a result he concludes that the temperature of the upper strata may well be perceptibly higher than that of the stratosphere. Ladenburg and Lehmann[15] found an ozone absorption band at 10μ. Also, Fowle[16] found a distinct absorption at 10μ in the solar spectrum which could not be ascribed to water vapor or carbon dioxide and which did not appear in his tube-work. This absorption band, occurring close to the maximum of terrestrial radiation and in the place where water-vapor absorption is weakest, must have a distinct tendency to increase surface-temperatures by the action of the "greenhouse effect"; but from existing data it would be difficult to determine the magnitude of this effect. Doubtless the near future will tell us much regarding the absorptive qualities of atmospheric ozone.

SUMMARY

In considering reasonable or possible changes in the composition of the atmosphere the following three would seem competent, if sufficiently long continued, to produce marked changes of climate:

[14] Proc. Phys. Soc., 39: part 1, Dec. 15, 1926.
[15] Ann. Physik, 21: 305 (1906).
[16] Ann. Astrophys. Obs. Smithsonian Inst., 4: 285.

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(1) A change in total cloudiness, provided all other factors remained unchanged.

(2) An increase in fine dust, such as was produced by the eruption of Mt. Katmai in 1912. This would effectively lower the temperature. A decrease in dust-content would not, however, be competent to produce the temperatures of warm geologic epochs.

(3) A large increase in the amount of ozone in the upper air would probably effectively lower surface-temperatures. As yet, however, exact data are unavailable regarding the formation of atmospheric ozone and regarding its ability to transmit radiation.

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THE GENERAL CIRCULATION OF THE ATMOSPHERE AS A CLIMATIC CONTROL

ALFRED J. HENRY

Meteorologists of the first half of the nineteenth century thought of the general atmospheric circulation as consisting essentially of a rising current of warm air in the tropics with an overflow poleward in the higher levels, a descent at the poles, and a return current on the surface of the Earth.

The modern notion, although it holds to the convective interchange between the equator and the poles, discards the idea of warm air rising in the tropics and flowing poleward and substitutes therefor a poleward flow of disconnected masses of warm air side by side with similar masses of cold polar air flowing equatorward. This interchange takes place for the most part through the action of traveling cyclones and anticyclones of the temperate latitudes.

The major climatic control. The interaction of these two differently directed masses of warm air and cold air, respectively, causes variations in weather and climate, best exemplified in temperate latitudes of the Earth; and it may be truly said that the temperature contrast between equatorial and polar regions is the major climatic control. This control is largely modified by the unequal distribution of land and water surfaces, so much so, that climates are divided into two great classes, viz, continental and marine.

The Northern Hemisphere, with about forty per cent of land surface, has a moderate continental climate; the Southern Hemisphere, with but seventeen per cent, has a fairly typical marine climate.

Ocean currents, largely initiated by the winds, as pointed out by

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Ferrel many years ago, are more effective as a climatic control than the winds themselves. The general effect of the atmospheric circulation is to equalize, so far as may be possible, the temperatures of continents and oceans, to cause large differences between the climates of the east sides as compared with the west sides of the continents—a difference that increases with the latitude—also, to produce wet and dry zones such as those in the trade-wind regions.

Semi-permanent cyclones and anticyclones. The general circulation of the atmosphere as modified by the rotation of the Earth on its axis creates in various parts of the globe six more or less permanent formations known as "Semi-permanent cyclones and anticyclones," each with its characteristic wind-circulation. Five of the six anticyclones are situated over the oceans, and the sixth over eastern Asia. The anticyclones are best developed over the oceans in late summer and over Siberia in winter. The semi-permanent cyclones are most fully developed in winter and over the oceans. The circulation of the atmosphere in these formations exercises an important influence upon the climate of the regions in which they are situated and over large bordering areas.

Unfortunately, the study of world weather, as such, is not yet fully within our grasp, although a beginning has been made in the publication of world-wide weather statistics in a single volume, that is, the *Reseau Mondial,* issued as Part V of the British Meteorological Yearbook.

It is a reasonable assumption that the general circulation of the atmosphere has not changed substantially in the last million years and that catastrophic changes in climate have not occurred within that time with the possible exception of a progressive desiccation in parts of Asia, reported upon by Huntington, and the pronounced lowering of the temperature of Greenland, which according to C. E. P. Brooks took place from about the fifth to the tenth or eleventh centuries of the Christian Era.

Climatic oscillations of the present are confined to restricted areas and are ephemeral in character; thus, southern Europe has recently experienced a series of about ten warm winters and the last winter in the United States was what may be the final one of a series of five mild winters. Changes of this character are short-lived and are doubtless due to small changes in the general trend of the larger atmospheric currents—changes that for the present, elude systematic observation and analysis.

It is conceivable that an increase or decrease in the intensity of the general circulation, however brought about, must affect the climate of the globe. In quite recent years not a little speculation has been indulged in as to the effect of an increase or decrease in the amount of

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solar energy received on the Earth's surface. It has been suggested that a rise in temperature in the tropics, accompanying increased solar-radiation would produce a horizontal flow of cold air from high latitudes and thereby tend to cool temperate regions; also, that in years with high solar-radiation, land areas in summer would be warmed to a greater degree than oceanic areas and thus tend to produce lower pressure over the continents and therefore an exchange of oceanic and continental air. This, however, would be but the normal condition of the continents in the summer.

It has been further suggested that variations in solar radiation in all probability would make themselves first felt in the higher levels of the atmosphere and thereby produce disturbances which in turn would induce changes in the lower layers. As heated air tends to rise rather than to sink, it is difficult to follow this suggestion.

The effect on the weather of changes in solar radiation, although apparently a simple problem, is far more complex than it would seem to be. Before definitive results can be reached, much more study is necessary.

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THE OCEAN AMONG THE FACTORS OF THE CONTROL OF CLIMATE

G. W. LITTLEHALES

Overspreading more than two-thirds of the surface of the globe, throughout all longitudes and nearly from pole to pole, in basins whose cubical content is fourteen-fold greater than the bulk of all the land of the world above sea-level, is a medium whose capacity for heat far outruns the like property in any other abundant substance in Nature. The place of water in the economy of Nature is most remarkable. Everywhere natural conditions are seen to be molded and influenced by its wonderful properties. Although it is nowhere told how much water there is in the world, there is no doubt that the presence in the oceanic basins of 324,000,000 cubic miles of this substance must constitute the ocean a dominant factor in geophysics, exercising through its circulation a governing influence upon heat transference and upon climate. Throughout the ocean's vast expanse of one hundred and forty million square miles, exceeding, by eighty million square miles, the total area of the land surface of the Earth, it is never in equilibrium, and, consequently, forever in reaction under stresses both external and internal, resulting in movement to bring about a redistribution of mass.

Internal forces are generated in the ocean whenever any change takes place in the physical properties of the water itself; that is, if either the

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temperature or the salinity is changed, then a dynamical reaction must arise and a redistribution of mass must ensue. The internal system of forces in an ocean are disturbed whenever it becomes the abode of organisms whose life processes alter the salinity, whenever the mass radiates or absorbs heat or undergoes evaporation, whenever precipitation from the atmosphere is received or the inflow of rivers takes place, or whenever internal physical transformation occurs as a result of turbulence and mixing.

It is in respect of temperature that the ocean exhibits some of its most remarkable characteristics. Over eighty per cent of its bulk remains at a temperature below 40° F. More than ninety per cent of the sea bottom is thus covered, including all those great tracts, in depths greater than 2000 fathoms, where the temperature is uniformly found to be within the range of a few degrees above the freezing point of fresh water. Salt water freezes at a lower temperature than fresh water: sea water with a salinity of thirty-five parts per thousand freezes at 28° F, and it is not uncommon to find temperatures but little above this in the waters of the polar seas. The office which the ocean performs in the economy of Nature by virtue of its saltness, it could not perform were its waters wholly fresh. About sixteen per cent of the entire ocean surface has a temperature below 40° F. In the surface waters of the lower latitudes there is a progressive rise in temperature, reaching the average of 81° near the Equator; but the position of the isothermal lines is much modified by prevailing winds, by the situation of land-masses, and by the distribution of areas of barometric maxima and minima. The warmer surface waters occupy only a comparatively small depth even in the tropics.

Although the mean daily variation of temperature in the surface waters of the open ocean is probably less than 1° F, the range from season to season may amount to 50° F in those regions, like the oceanic areas around Newfoundland, Japan, and the Cape of Good Hope, where the surface is occupied successively by waters of polar and equatorial origin; but on the other hand, there are very extensive regions both in the tropical and polar waters where the range does not exceed a few degrees during the course of the year. With descent into the depths, the seasonal changes tend rapidly to diminish.

It is in the aerial ocean overlaying the marine ocean that the prime mover in oceanic circulation is found. Operating around regions of barometric maxima in the eastern part of the temperate zone, both north and south of the equator, in all the oceans, where action-centers exist through the accumulation of more than the average amount of the Earth's

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atmosphere, the winds induce surface currents in the ocean that move in a clock-wise circuit in the northern hemisphere and in an anti-clock-wise circuit in the southern hemisphere, with modifications brought about by the influence of atmospheric centers of action where there is less than average amount of the Earth's atmosphere, as obtains near Iceland, near the Aleutian Islands in winter, and in the polar borders of the south temperate zone, and yet others where there is alternately less or more of of the Earth's atmosphere, as obtains over the continent of Asia. In the trade-wind regions, evaporation is very great and hence the salinity of the surface waters is high; but as the temperature is also high in these regions, the highly saline water remains at the surface during its westward drift in the tropical region on both sides of the equator and thence poleward in the western part of the oceans until, by reduction in temperature, the density becomes greater than that of the surrounding waters. The systematically varying distribution of salinity and temperature giving rise to a systematic distribution of density or heaviness of the waters, is one of the basic factors in the sub-surface or inner circulation of the ocean, causing a systematic descent from the surface of the heavier waters which characterize the middle latitudes and a slow movement thence to the deeper waters, entirely distinct from the oscillations of the mass of the ocean set up by seiches and tides both toward the pole and toward the equator, where ascending currents rise from the depths. The characteristics of this system of circulation may be interpreted by profiles showing the distribution of temperature in the depths and confirmed by profiles showing the distribution of oxygen in the depths. In the former, the isothermal lines show a pronounced downward trend in the middle latitudes and a pronounced upward trend in the equatorial regions; and in the latter, it is evident that the waters in the depths of the ocean in the equatorial regions have been much longer out of contact with the atmosphere than the waters of the temperature latitudes which, descending from recent contact with the atmosphere, contain by absorption about three times as much oxygen as the deep equatorial waters which have ascended from the depths at the close of the long circuit of the bottom waters toward the equator. The pressure caused by the weight of the elevated masses about to be described, being transmitted to the bottom of the ocean, has the effect of intensifying these deep poleward and equatorward movements.

These massive movements are in striking contrast to the relatively rapid rate of motion of the surface currents impelled for the main part in general accord with the anti-cyclonic circuit of the winds, which, in their direct and indirect effects taken in conjunction with the configura-

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tion of the continents, constitute the prime agency in originating and maintaining the circulation of the ocean.

The movement of the surface drift is communicated by friction and vertical interchange of water to the underlying layers, but owing to the rotation of the globe, the surface current caused by a steady wind is inclined to the wind's direction at an angle of 45°, to the right in the northern hemisphere and to the left in southern hemisphere. With descent beneath the surface, the currents deviate more and more from the winds, and the main mass of the water moves at right angles to the direction of the wind. Consider now the case of the action-centers of high barometric pressure around which the winds circulate in a clockwise direction in the northern hemisphere and in an anti-clockwise direction in the southern hemisphere. In the northern hemisphere, all these winds will be driving the water to the right and in the southern hemisphere to the left, that is, toward the center of the system in each case. The result is that the water is piled up in the center into an elevation down the slopes of which the water will run. The rotation of the globe will deviate the water to the right in the northern hemisphere and to the left in the southern hemisphere, and when a steady state is reached it will be flowing around the central elevation in a clockwise direction in the northern hemisphere and in an anti-clockwise direction in the southern hemisphere.

As a consequence of this circulation, heat is conveyed by the route of the western and polar borders of the oceans across the planetary zones. For instance, in the North Atlantic Ocean, the waters of the tropics is born far beyond the Arctic Circle to the shores of Spitzbergen. The world-isotherms show how the temperature along the northwest coast of Europe is thus affected.

In concomitance with the penetration of warm water into the polar regions, there is a penetration of polar water into the lower latitudes in all the oceans. Where the warm waters that reach Spitzbergen and Novaya Zemblya are disappearing beneath the lighter waters, discharged upon the Arctic Ocean from the great rivers of the northern continents, these ice-bearing waters are moving westward to form the East-Greenland Current which becomes an important accessory to the Labrador Current, whose waters reach the vicinity of the 40th degree parallel of latitude and there in conflict with the equatorial waters create vigorous convection and a true action-center of oceanographical influence.

It has long been known that the mere nearness of warm water has not a decisive action on climate, but that it is made effective by the winds that blow over it. During eight months of the year from the end of

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August to the beginning of May, in nearly all parts of the North Atlantic Ocean the temperature of the surface water is higher than the temperature of the air whose sweep in middle and northern latitudes is toward the European side.

An impression of the order of magnitude of these quantities may be gathered from estimates that have been made in relation to the Atlantic Ocean. The Antilles Current conveys nearly forty cubic miles of water an hour past Porto Rico; and, in the Florida Strait, the Gulf Stream conveys about fifteen cubic miles an hour, moving with a speed of three miles per hour. The combined Florida and Antilles currents move northward to Cape Hatteras with an average velocity of seventy miles per day in the center and half this amount on the edges. Off Cape Hatteras is the so-called "Delta of the Gulf Stream," where it begins to separate into several branches. South of Nova Scotia the velocity is about thirty-eight miles a day. At the southeastern and southern edge of the Grand Bank of Newfoundland, the Gulf Stream comes into conflict with the cold southward-flowing Labrador Current, which greatly lowers its temperature. The average temperature of the water flowing towards Europe after passing the Grand Bank is 10° to 15° F lower than the temperature of the Gulf Stream off Cape Hatteras.

Off the Grand Bank of Newfoundland, the Gulf Stream divides into several branches: the most northerly flows toward west Greenland, another flows toward Iceland, and a third containing the main body of the water flows toward Europe and the Mediterranean Sea, again dividing in about 40° north and 40° west into two branches. The southern branch turns southeastward skirting the coast of southwestern Europe and Africa as a cold current. The northern branch gaining renewed velocity from the prevailing southwesterly winds crosses the Atlantic with an average speed of twelve miles a day and bathes the shores of western and northwestern Europe. The bulk of the water passes north of Ireland and Scotland. Under the influence of the prevailing southerly winds, the larger part of this water drifts along the Norwegian coast to Novaya Zemblya where it is largely overlain by colder, but fresher water and loses its identity, but some of it remains on the surface to reach Spitzbergen giving rise to the relatively favorable climate of that land and keeping almost free of ice its western coast. The volume of this stream of Atlantic water passing along the coast of Norway is about one-quarter of a cubic mile an hour in the latitude of the Lofoten Islands. Even this amount, small compared with the volume of the Gulf Stream off the Atlantic coast of the United States, exercises climatic influences that have important effects upon the Norwegian harvests.

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The influence of the marine ocean upon climate is exercised jointly with the aerial ocean above it. The former is the conservator of heat and the conveyor by which it is delivered to distant regions, to be distributed by the latter through the agency of the winds.

A tract of the ocean 450 miles square and one-tenth of a mile deep, in being reduced one degree in temperature, would give off enough heat to raise the temperature of the atmosphere 10° over the whole of the United States up to a height of two miles.

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THE CRITICAL EXTENT OF POLAR ICE-CAPS

L. H. Adams

(Abstract)

This is a brief review of our present knowledge concerning one aspect of climatic control. The subject is of importance in connection with certain phases of geology such as glaciation and the Wegener hypothesis. According to this hypothesis the continents at various times have drifted apart in an east-west direction and have also experienced large movements from south to north and from north to south again. This latter feature of Wegener's theory is supported by climatological evidence, and loses its only support if other means of securing large variations in climate are found.

Considerable attention has been given to the possible physical factors which might explain variations in climate during past ages. Among the factors studied have been: Variations in the eccentricity of the Earth's orbit and in the inclination of its axis; changes in the amount of water vapor, carbon dioxide, and dust in the Earth's atmosphere; and variability in the amount of heat radiated from the Sun. Most of these factors are doubtless of importance, but it is not easy to understand how they can produce the radical changes in the Earth's climate, which have occurred so many times during geologic history.

The theory of polar ice-caps as developed by Kerner and by Brooks is as follows: The climate on the Earth is either glacial or non-glacial. The non-glacial is the usual or normal type of climate. During non-glacial periods the polar region had no great ice-sheets; the temperature in these regions was approximately the same as we have today in the temperate zone. The rarer glacial periods were distinguished by a much lower temperature. The extreme north and south parts of the Earth were covered with ice-caps which sometimes extended to middle

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latitudes. Now suppose that at the North Pole the temperature is low enough for a small ice-cap to form. As soon as the sheet of ice formed it would cause the temperature to fall because of the high reflecting power of the ice (about four-fifths of the Sun's radiant energy being reflected back into space). This would cause more ice to form, thus increasing the area of the ice-cap, which would still further lower the temperature, and so on.

A small initial lowering of temperature would, therefore, be capable of producing a polar ice-cap of very considerable extent. The exact effect depends primarily upon the normal horizontal temperature-gradient; that is, upon the normal variation of temperature with latitude, and upon the additional cooling produced by each square kilometer of ice newly formed. The first effect is proportional to the radius of the cap and the second to the square of the radius, and it is for this reason that a cap, having once been well started, would grow at an increasing rate.

From such data as are available it appears that, starting with a non-glacial condition, that is, with an Earth having no large permanent ice-fields, it is possible for an initial lowering of temperature of only 0.3° C to produce eventually an ice-cap extending to 65° latitude. In general, whenever the mean temperature at the poles is close to the freezing point of sea-water, a critical condition exists such that a very small change of temperature can cause a most profound change in the extent of ice-fields. A change in temperature initiated by any one of the supposed factors, such as atmospheric dust or change in the solar constant, causes the temperature to jump from one state to the other, and it is only the very slow change in these factors which prevents the transition from glacial to non-glacial states from being more rapid. It is of interest that according to this theory an increase in the Earth's mean annual temperature of one degree or two degrees centigrade would cause the present polar ice-caps to disappear.

Such calculations as these are subject to many uncertainties. Many of the factors involved are not amenable to precise evaluation. The theory of the critical extent of polar ice-caps is to be considered as a qualitative generalization rather than as a quantitative law. And yet, it would seem that a recognition of the general applicability of this theory would allow the problem of ice-ages and of radical changes in climate to approach a satisfactory solution.

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CHANGES IN ELEVATION OF THE ROCKY MOUNTAINS IN PLEISTOCENE TIME AS POSSIBLE CLIMATIC FACTORS

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It is well known that the Sierra Nevada and Cascade ranges intercept moisture from the Pacific, causing it to be precipitated on their western slopes with resulting arid or semi-arid conditions east of them. In a less degree the Rocky Mountains effect a similar result, particularly north of the latitude of Yellowstone Park. Precipitation on their western sides or westernmost ranges, such as the Clearwater Mountains, Cœr d'Alene, Cabinet, and Purcell ranges is much greater than on the ranges farther east or the plains beyond. It follows that if the intercepting ranges were removed or even lowered considerably, the interior plateaus and the great plains in northern United States and Canada would receive an increased precipitation which, of course, would be one of the factors necessary to renewed glaciation. In this connection, it is noteworthy, perhaps, that in the Olympic Mountains, which receive a heavy precipitation, permanent snow and ice-fields are rather general above an altitude of five thousand feet. Farther east in the same latitude, the present lower ice-limit rises as the precipitation decreases. In Glacier Park it is at least seven thousand feet.

The present heights of the Cascade Range and the Rocky Mountains are due almost wholly to crustal movements that have occurred since the Miocene. There were older mountains, but they had been generally lowered by erosion before the movements producing the present mountains began. According to Smith and Willis,[1] the present Cascade Mountains were elevated in Pleistocene or at least post-Pliocene time, and this view is supported by the uplifted position of the Pleistocene Satsop formation described by Bretz.[2] Since then there have been oscillations of at least two hundred and ninety feet in the level of the strand-line in the Puget Sound region.[3]

In the Columbia Valley, evidences are found of a water body that existed briefly during the later or Wisconsin part of the Pleistocene; and this body is interpreted as the result of depression which reached a

[1] GEORGE OTIS SMITH and BAILEY WILLIS. Contributions to the geology of Washington. U. S. Geol. Survey Prof. Paper 19: 28, 38, 92 (1903).

[2] J. HARLEN BRETZ. The Satsop formation of Oregon and Washington. J. Geol., 25: 446-458 (1917).

[3] J. HARLEN BRETZ. Glaciation of the Puget Sound region. Wash. Geol. Survey Bull., 8: 231-239 (1913).

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maximum of twelve hundred feet or more.[4] The depressed area doubtless included the Cascade Mountains and possibly parts of the Rocky Mountains also.

The northern Rocky Mountains are made up of many more or less detached or individual ranges and plateau-like masses. All of them have been rather deeply and maturely dissected by streams, but most of them still preserve even crest lines or flat-topped summits that suggest ancient peneplains or other surfaces of small relief that were developed by erosion at low altitudes. To form the present mountains, the old surface was elevated differentially. In southwestern Montana, it was warped and broken into fault-blocks, some of which were raised and others depressed. These movements were almost wholly post-Miocene and locally at least they have continued into Pleistocene and Recent time.[5]

The studies of Alden[6] and others in the northern Great Plains show a succession of regional uplifts during late Tertiary and Pleistocene time that in places aggregate one thousand feet or more. One of these, probably of less magnitude, was an early Wisconsin uplift that immediately preceded or attended the advance of the Keewatin ice. There has also been a post-Wisconsin uplift, the influence of which is still felt by the streams. The movements described by Alden were regional and occurred in the same period as the differential uplifts in the mountains. The regional elevation was periodic and progressive and since the beginning of the Pleistocene has caused a net gain in altitude of the mountain crests, for, in the more western ranges at least, they still carry remnants of the old low erosion surface.

Uplift may be regarded as a cause of glaciation provided the uplifted and glaciated areas are the same. On the other hand uplift might, by cutting off or diverting the flow of moisture, stop the accumulation of ice in a neighboring area or shift the locus of glaciation to another place.

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[4] J. HARLEN BRETZ. The Late Pleistocene submergence in the Columbia Valley of Oregon and Washington. J. Geol., 27: 489-506 (1919).

[5] A paper in preparation by the author, entitled "Late Tertiary and Quaternary faults in southwestern Montana," describes the Continental Fault near Butte, a fault at the east foot of Bitterroot Range, and a fault at the west foot of Madison Range, Montana, on all of which upward movements of the adjoining mountain-masses have occurred in very late geologic time. A scarp produced by movements on the fault at the base of Madison Range cuts across moraines of the Wisconsin stage, later alluvial deposits, and has an appearance of newness that suggests an age to be measured in scores or at most a few hundreds of years.

[6] W. C. ALDEN. Physiographic development of the northern Great Plains. Geol. Soc. Amer. Bull., 35: 385-424 (1924).

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The evidence so far available shows that during the Pleistocene, the Cordilleran area here considered was far removed from a condition of crustal stability and is even yet, as it were, quite alive. It seems most probable, therefore, that the changes in the mountains' heights from time to time must have exerted a strong, possibly a controlling, influence on the growth and changes in position of the great glaciers in the regions of Keewatin and Hudson Bay.

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SOME POST-TERTIARY CHANGES IN ALASKA OF CLIMATIC SIGNIFICANCE[1]

PHILIP S. SMITH

Discussion of relatively late changes in Alaska that may have had climatic significance is much hampered by the lack of specific information relating to many of the pertinent factors, but even then it is too large a topic to touch more than the fringes of in the short time allotted.

One of the speculations that crops up periodically both in its relation to climate and to migrations of animals and plants, is the inquiry into what would be the result if the region near Bering Strait had been at one time more depressed or more elevated than at present. The details of the situation that would have been produced can not be stated with finality, but it seems doubtful whether possible changes of this sort would have effected as radical physical differences as might be conjectured from the casual inspection of an ordinary map. The reason for this conclusion is, that unless depression exceeded 2,300 feet the Strait would maintain practically its present width as the portals at Cape Prince of Wales and at East Cape rise abruptly to elevations of 2,300 and 2,521 feet, respectively, and in the midst of the Strait are three islands, the largest of which is from three to four miles in diameter and has a height of 1,759 feet above the sea. In Seward Peninsula there are no deposits or other evidence that even remotely suggest that the region has been submerged two thousand feet below its present stand during Tertiary time or later.

Furthermore, much of Bering Sea and the Arctic Ocean between Alaska and Asia is really part of a land-mass rather than part of an oceanic area. This can be clearly seen from the map (Figure 1) in which areas lying between sea-level and a depth of thirty fathoms, between thirty fathoms and one hundred fathoms, and from one hundred fathoms down, are indicated by distinct tints. From this map it will be seen that, on the whole, the two continents are separated by only a shallow sea; or,

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FIG. 1

Depths of water in Bering Sea and parts of Arctic Ocean.
(Depths in Pacific Ocean not shown)

to put it another way, are practically connected except for a slight submergence. Therefore, even if the Aleutian Islands were completely removed, the "continental area," if I may use that term, would extend as far south as the Pribilof Islands and as far north as latitude 72°. This land-mass is believed to be of relatively great age. Though the surface of some of the submerged area is doubtless formed of relatively late detritus brought down to the sea by the Yukon and Kuskokwin rivers,

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that source is entirely inadequate to explain the larger feature which is more than one thousand miles wide.

The evidence of past glaciation contrasted with present glaciation in extent and relationship to the mountain-masses in which it originated leaves little room to doubt that both were controlled by essentially the same general conditions as now prevail in the matter of wind-direction, and of atmospheric and oceanic circulation. In other words, the glaciers of the recent past were relatively proportional to those of the present, and on opposite sides of ranges had in general the same differences as are observed in existing glaciers. There is, therefore, small likelihood that in the late past, Pacific-Ocean circulation into the Arctic Ocean was notably different from what it is today.

It is, however a significant fact, but one which still awaits explanation, that the maximum glaciation in the past in Alaska covered in area only fifteen to seventeen times as great as the existing glaciation. Few of the past glaciers in Alaska appear to have extended for an airline distance of more than 150 miles from the crest of the ranges in which they originated, whereas in eastern North America they extended many times that distance. This striking and apparently anomalous difference in amount of glaciation warrants further search for data regarding the synchroneity of glaciation in the two regions. Capps, who is the only one to publish on this subject, has given facts which suggest that the maximum extent of ice in one of the valleys in eastern central Alaska was about 125,000 to 150,000 years ago, which he considers indicates general contemporaneity with the Wisconsin stage in the States.

In suggesting the general stability of Bering Straits it was not intended to imply that Alaska has long stood inert in its present physical form. Evidence is almost universally present showing that in different parts it has been subjected to movements of uplift and depression. These movements mark both broad regional warpings and localized mountain building. Former higher stands of the land are relatively obscure because many of the deposits and other kinds of geologic evidence that mark these movements are now buried under the sea or masked by later processes and products. Certain it is, however, that near Nome the country stood, in late Tertiary times, at least 150 feet higher than it now does because at that place buried beaches have been recognized to that distance below sea-level.

In the present inquiry, however, former higher stands of the land are not of as much immediate significance as former lower stands and evidence of these is much more legible and widespread. From many parts of Alaska, data have been obtained that prove relatively recent uplifts amounting to hundreds if not thousands of feet. This does not mean

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that uniform uplifts of these amounts are recognized, for even within short distances the amount of the same uplift varied greatly. For instance, Brooks described an old marine plain in southwestern Seward Peninsula that in places stands as much as 600 feet above sea-level, but that in other places, not more than 50 miles distant, now stands below sea-level. Obviously the evidence regarding former lower stands of the land becomes progressively less distinct the higher the old land-surface has been uplifted; because the higher ones are usually more vigorously attacked by erosive processes and generally are older than the lower ones and consequently have been longer exposed to attack. At many places all the way from southeastern Alaska to the extreme northern part, evidences of relatively recent uplift are fairly distinct, up to six hundred feet, and in selected places up to one thousand feet. The highest uplift that has been definitely determined is in the St. Elias region, where Russell and Maddren describe a marine deposit containing fossils of Pleistocene age that now stands three thousand or possibly five thousand feet above the sea.

Although by no means susceptible of precise measurement relative to sea-level, the geologic evidence within the Alaska Range indicates an uplift, in that tract, of many thousand feet in Tertiary and later time. Briefly, the great arc now marking the Alaska Range had relatively low relief in the early Tertiary, as coal-beds and fine sediments extend far into the present mountain-mass. Subsequently deformation took place whereby these early beds were bent until they now stand vertical or even overturned. These beds are now preserved mainly in the bowls of synclines, the higher parts of the folds which at one time formed the mountain peaks having been removed by erosion so that it is impossible to determine the maximum height to which these beds at that time rose. Concomitantly with the growth of the mountains, erosion became vigorous and great bodies of coarse material were eroded from the growing mountain-mass and deposited near their flanks. In places these gravels have a measured thickness of two thousand feet, so that uplift within the ranges amounting to at least that amount must have taken place, though, of course, the gradients of streams that laid these deposits down were probably steeper than those of the present streams. Although these deposits were not laid down at sea-level, the fact that they now occur in peaks rising to elevations of more than four thousand feet above the sea, while it does not give the exact measure of the uplift, does serve to indicate that they have been raised several thousand feet. The growth of the mountains is still going on, as is shown by the earthquakes that occur in them and by the recently raised beaches, such as those described by Tarr and Martin, on their flanks. It would strain the credulity of the geolo-

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gists who have worked in the Alaska Range to believe that that mountain chain had only slight topographic strength in the late Tertiary; but that parts of it stood several thousand feet lower than now, is in entire accord with all the known facts. Analysis of the effects on climate which such a decrease in elevation would produce must be left to our brethren skilled in climatological research.

U. S. Geological Survey,
Washington, D. C.

PLEISTOCENE AND RECENT TOPOGRAPHIC CHANGES IN THE PACIFIC COAST STATES

JOHN P. BUWALDA

Advance Summary.—In comparison with the eastern half of North America, great topographic changes have occurred in the Pacific Coast States during the last three periods of geological time—the Pliocene, Pleistocene, and Recent. During these later periods of geological history the eastern mountains and plains have apparently suffered only relatively gentle upbowing or downwarping, but since the beginning of the Pliocene the western mountains and plateaus have not merely been uplifted thousands of feet but have been strongly folded and broken by faults. In the West, neighboring areas have moved in opposite directions. Some have gone up great distances and now form the high ranges; others have sunk and now either form the valleys into which the erosional detritus from the ranges is being in part deposited or they form estuaries or sounds if, lying near the Coast, they sank below sea-level.

While mountains existed in the west before the Pliocene, the great barriers of today have come into existence mainly during and since the beginning of that period. The duration of the Pleistocene and the Recent together was very much less than the Pliocene. The larger part of the growth of our present mountains was accomplished in the Pliocene, but very notable topographic changes occurred also in the Pleistocene and Recent.

It seems obvious that if the West Coast mountains have any effect on the climate of the interior of North America, marked changes in their altitude would result to at least some degree in changes in the climate they influence.

GENERAL GEOGRAPHY OF THE PACIFIC COAST REGION

As is well known, that part of the United States lying west of the Rocky Mountains is divisible topographically into four north-south belts. Skirting the shore of the Pacific lie the Coast Ranges, extending from southern California to the Canadian boundary. Their width is usually

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not over a few tens of miles and their height, excepting in three areas, is usually less than three thousand feet. To the east of the Coast Ranges lies a north-south line of valleys; these from Canada southward are the Puget Sound, Cowlitz, Willamette, Rogue, Sacramento-San Joaquin, Mohave Desert, and Salton Sink depressions. In Washington and Oregon the Cascades border this depression on the east; in California the Sierra Nevada occupy a corresponding position along most of the inland margin of the State. Extending eastward from the Cascades and Sierras is the desert region, usually known as the Great Basin, areally larger than the whole country to the west of it, and reaching to the base of the Rockies.

MOVEMENTS ALONG CALIFORNIA COAST

Pleistocene changes in relative level of land and sea along the California Coast are indicated by physiographic evidence and by position of Pliocene strata bearing marine fossils. At numerous places, notably south of San Francisco, at Santa Cruz, at San Pedro Hill near Los Angeles, and in the San Diego region, old strand-lines and marine terraces representing the ancient sea-floor, form steps from the present strand well up toward, or even attaining, the hill- or mountain-tops. They indicate intermittent uplift totalling not less than 1500 feet. The highest marine terraces are faint in their features, and it is possible that still higher ones originally existed but have been destroyed by erosion. They are not continuous at the same level along the Coast, however. Some stretches of the shore show evidence of submergence of at least some hundreds of feet. San Francisco Bay resulted from drowning through subsidence of a considerable stretch of the Coast. These uplifts and depressions were mainly Pleistocene in date. On the terraces are found the shells of organisms which lived on the ocean-floor before its emergence; they are largely living species. Where submergence has occurred it has been so late in geological time that the waves have modified the newly-established shores but little.

Pliocene marine sediments along the Coast bear out the evidence of the terraces, although the movements which tilted these strata were apparently often earlier than the terrace-forming uplifts. The uplifts and depressions were, however, largely post-Pliocene, and were of magnitudes comparable to those indicated by the terraces.

Less is known of the changes of level of the Washington and Oregon coasts. Terraces have been recognized, however, at many places and marine strata in a tilted position and of late geological age. It is clear that the northwest coast has undergone vertical movements comparable to those of the California Coast. The old strand-lines occur many hun-

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dreds of feet above sea-level. Their Pleistocene age is attested by their preservation, even in the heavy rainfall of that region, and by the fossils found on them.

MOVEMENTS WITHIN THE COAST RANGES

Three very precise surveys in the California Coast Ranges by the Coast and Geodetic Survey, spaced approximately twenty-five years apart, have shown that peaks serving as triangulation points have moved in the intervals as much as twenty feet horizontally. These movements have probably been proceeding for a long time in the past and the aggregate displacements may be measured in miles or tens of miles. Vertical displacements of neighboring blocks with reference to each other are apparently not occurring at the present time so actively as horizontal shifting; but high scarps, particularly in southern California, attest to such displacements in very recent times. North of Pasadena and north of San Bernardino, and at other points, mountain-faces rise very steeply and boldly to heights of five to eight thousand feet above the adjoining plain. The slight degree of dissection by the erosional agencies indicates clearly that the uplifts occurred largely in Pleistocene and Recent time. Middle Pliocene strata cut by the fault of plane of breaking corroborate the late Pliocene and post-Pliocene dates of the movements. However, the peaks of these mountains had already reached approximately their present height in late Pleistocene time, for glaciation affected them. The evidence indicates, therefore, that most of the vertical mountain-making movements occurred during later Pliocene time, and only a smaller part during the Pleistocene or Glacial period and the Recent period.

There is some reason to think that parts at least of the Coast Ranges may have been higher in late Pliocene time than they are now, and that hence during the Pleistocene they have been reduced somewhat in elevation. The folds raised in middle Pliocene time, of which only the roots remain now, would form high mountains, and it is possible that since about middle Pliocene time the general change in relief has been one of reduction of heights by erosion at a rate more rapid than the rate of uplift.

PACIFIC VALLEY DEPRESSION

While the Coast Ranges of California, Oregon, and Washington experienced uplift during the Pleistocene, the valleys lying to the east of them clearly were depressed. Puget Sound, in northwestern Washington, is a great river-valley system, with its branching arms, which was depressed and drowned by the sea. It probably sank not less than a thousand feet. The Willamette Valley has likewise been bowed down to some degree,

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in northwestern Oregon, and Pleistocene sediments spread thickly over its floor as a consequence.

In California, the Sacramento-San Joaquin Valley has been warped downward while the adjoining mountains rose. Part of this depression doubtless occurred during the Pleistocene, although the larger part of it seems to antedate this period somewhat. And the same may be said for the Salton Sink depression; it is in part Pleistocene in date of origin.

CASCADE MOUNTAINS AND SIERRA NEVADA

With the possible exception of the Rocky Mountains, these two ranges form the most effective barrier in the western United States for influencing climate. Lying end to end, they extend from the Canadian boundary to southern California, the south end of the Sierras terminating approximately at the southern margin of the belt of prevailing westerly winds.

The Cascades maintain a height of five to seven thousand feet practically throughout their length from Canada to northern California and the Sierras continue southward with about that elevation from northern California to central California, in the region about Lake Tahoe. From this point southward they rise from seven to about fourteen thousand feet in the Mt. Whitney region, south of which they descend again to three or four thousand feet.

The west slopes of these two ranges are heavily timbered and receive heavy precipitation. The east slopes are relatively dry and look out over the vast dry expanses known as the Great American Desert, the arid condition of which results mainly from the abstraction by these ranges of the moisture which the west winds from the Pacific would otherwise bear farther inland. The ranges create rain-shadow areas. The temperature conditions on the two sides of these ranges are likewise very different.

The geologic date of uplift of these two ranges is probably about the same, if we may judge by the canyons cut in them since the beginning of their growth, and by stratigraphic evidence. They are probably both still rising, moreover, as attested by earthquakes. In 1872 a slip of several feet on a fault at the east base of the Sierras in Owens Valley was doubtless a detail of this upward movement. Lower Pliocene, and perhaps younger strata, have been disturbed along the bases of the ranges, so that it appears that the initiation of their latest elevation occurred in post-lower Pliocene time. Both ranges had, however, reached approximately their present height by the Glacial period, at least by the latter part of it, for they show strongly the evidence of having borne large ice-streams in their higher parts. Moraines found along their eastern base indicate that the Sierras probably stood at approximately their present height during the last two, and perhaps the last three, of the advances

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of the Pleistocene ice. The Cascades are likewise strongly glaciated. It is clear that the major part of the uplift of these ranges had been accomplished by middle Pleistocene time.

In connection with the effect of these ranges upon the climate of the country to the east, it is of interest to note that the level of maximum precipitation is about seven thousand feet on the west slope of the Sierras. This would apparently indicate that for each additional thousand feet increase in height of the mountains above the seven thousand feet level, the corresponding additional effect upon the climate to the east would be less.

GREAT BASIN PROVINCE

The region between the Cascades and the Sierras on the west, and the Rockies on the east, lies in general lower than the western ranges bordering it, and it hence has no such marked effect upon the climate of regions to the east. But it is interesting to note that this immense desert province, larger in area than the whole region lying west of it, is apparently still being actively deformed with resulting changes of level. One range in Nevada has been uplifted within historic times, with slipping on the fault bounding it to the extent of several feet. Bold fault-scarps in southeastern and northeastern Oregon, and occasional earthquakes in eastern Washington, indicate clearly that the growth of the separate mountain-masses lying within the Great American Desert is still in progress. But here again, as in the case of the Cascades and Sierras, the larger part of the movements which created the ranges appear to have occurred before the last glacial advances. The summit regions of a number of the ranges were vigorously glaciated. Clear evidence of post-glacial faulting and uplift is presented at a number of places, but the movements were not large in magnitude.

CONCLUSION

Evidence from physiography, structural geology, and paleontology combines to demonstrate that uplifts of hundreds of feet, and in some areas, probably thousands of feet, have occurred in our Pacific Coast mountain belts since the beginning of Pleistocene time. Depressions of hundreds of feet have occurred in some other localities. The movements are continuing today, possibly as actively and rapidly in many places as at any time in the past. This latter fact merely tends to emphasize the recency of many of the larger changes in level and topography. A large part of the changes in level had been accomplished before at least the last two dates of advance of the ice during the Pleistocene.

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SECTION OF GEODESY

(Washington, D. C., April 28, 1927)

RECENT PROGRESS OF CANADIAN GEODESY

NOEL J. OGILVIE

Exhaustive field tests and study have been made during the past two years of a 3¾-inch transit (see Figure 1). This small instrument, 12¾ pounds, is capable of measuring angles with primary accuracy when used within the limits of its telescope-power, maintains its ad-

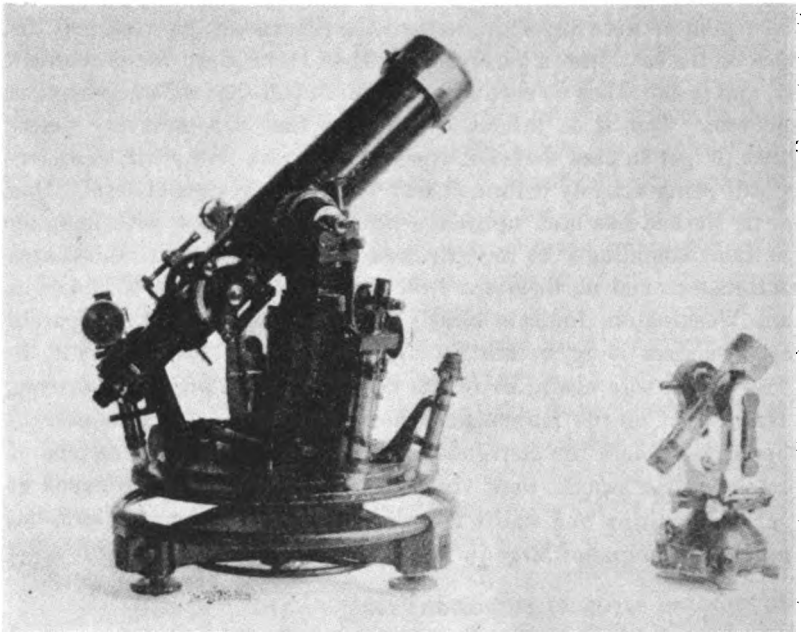

FIG. 1

Twelve-inch theodolite and three-and-three-quarter-inch theodolite, Geodetic Survey of Canada.

justments under exceptionally strenuous conditions and can be manipulated in about one-half the time occupied with twelve-inch, three-micrometer transits.

The telescope objective is only 40 mm in diameter, which is inadequate under hazy atmospheric conditions, but four transits of a similar design with 60-mm objectives, 5½-inch glass horizontal circles and weighing in their cases about 30 pounds each will shortly be delivered (see Figure

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2). It is anticipated that this design will fulfil all requirements of work for which a twelve-inch instrument was formerly thought necessary.

In precise levelling a development, which it is believed will ensure greater permanency and convenience to the public is the construction, at certain specified points, of monuments of a new and enlarged type to be known as the "fundamental bench-mark" (see Figure 3).

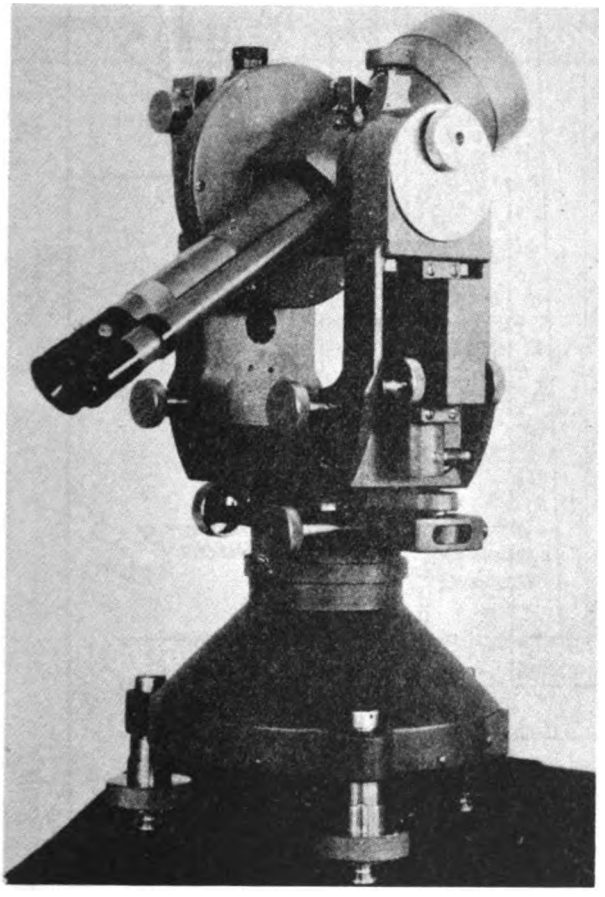

FIG. 2

New large model five-and-one-half-inch theodolite (weight 23 pounds), Geodetic Survey of Canada.

The intention is to build these in the cities and more important towns and junction points, and each monument will be considered as the governing bench-mark for the town and surrounding district. The monument, whenever possible, will be constructed in a park or public square, the selection of the site being carried out in collaboration with the municipal authorities in order that, as far as can be foreseen, the location chosen shall be free from disturbance in the future by reason of building, grading operations, or other changes.

The actual monument or "fundamental bench-mark" is constructed of concrete and takes the form of a frustum of a pyramid, two feet square at the base, one and one-half feet square at the top, and seven feet in

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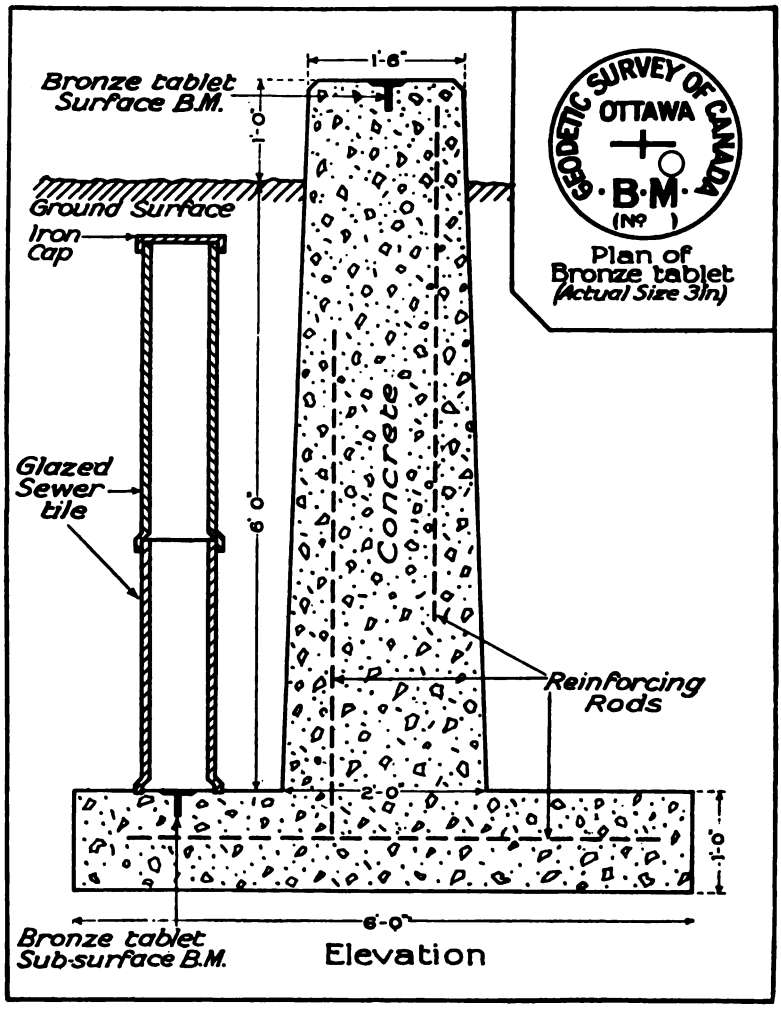

FIG. 3

Fundamental bench-mark, Geodetic Survey of Canada.

height, and is reinforced with four twisted steel rods. The excavation for the structure is carried to such a depth that only from twelve to fifteen inches of the column projects above the natural ground-surface; it rests on a circular concrete base six feet in diameter and one foot thick, reinforced by steel rods placed radially, the base and column being constructed as a monolith.

A bronze tablet of standard form is set vertically in the top of the

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monument and the elevation for this is listed as the elevation of the "fundamental bench-mark." In order, however, to provide for the recovery of the elevation, should the tablet or the top portion of the monument be damaged, a second tablet, known as the subsurface mark, is set in the concrete base at one side of the column. This is protected by means of two sections of six-inch sewer tile, reaching to within a

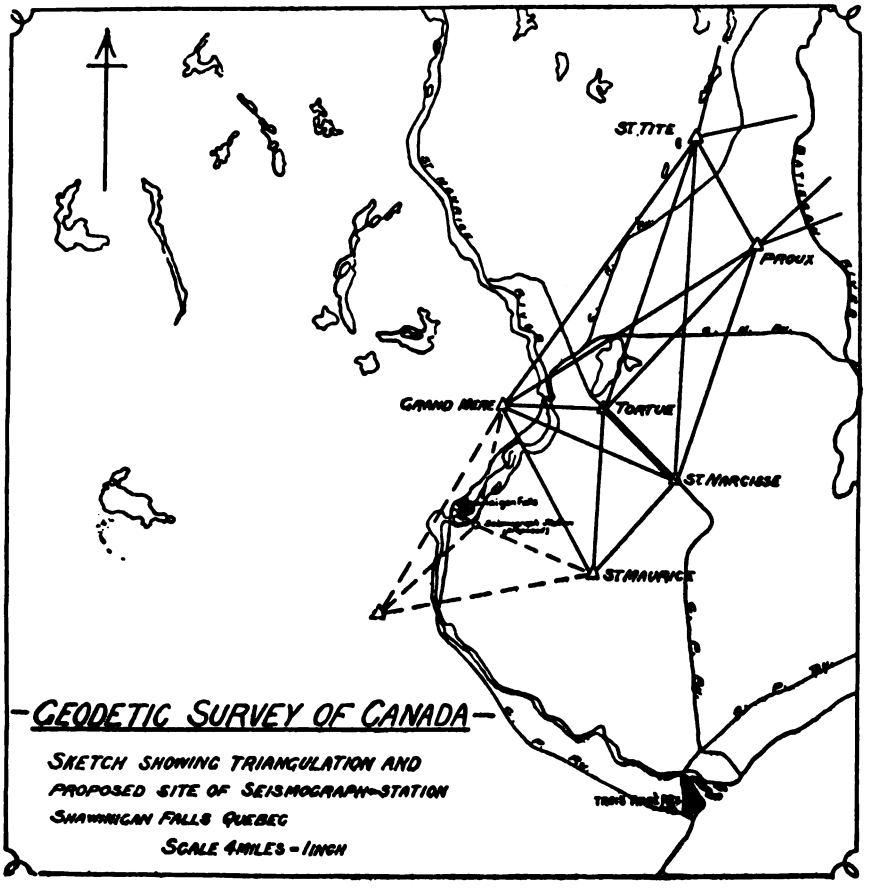

FIG. 4

Sketch showing triangulation and proposed site of seismograph-station at Shawinigan Falls, Quebec, Geodetic Survey of Canada.

foot of the ground surface and closed with a metal or concrete cover. The filling in and grading of the earth around the column conceals this from sight.

Two schemes of triangulation were observed in 1926 at Seven Falls and Shawinigan Falls (see Figure 4) in the Province of Quebec with

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the express purpose of cooperating with local industrial concerns in a study of seismic disturbances and resulting earth-movements. The triangulation is continuous with the first-order work of the St. Lawrence river, and covers in each case the industrial locality and surrounding area of about seventy-five square miles, where slight earth-movements and damage to buildings resulted from the earthquake of 1925.[1]

The geodesist has proved the theory of isostasy to be a scientific fact from the result of measurements made in various areas of the Earth's surface, and the general conclusion is justified that isostasy prevails throughout the Earth's crust.

During the coming summer a comprehensive programme of astronomic determinations, extending across the continent, will be initiated at various triangulation stations covering a non-continuous belt of about four thousand miles (see Figures 5 and 6).

The results of these astronomic determinations are expected to sustain the value of the depth of compensation; but in addition an important field of study will be opened with regard to the influence of local topography and in consequence the extent of the regional compensation.

Considerable progress has been made along the lines of research and adjustments. Publications are being prepared dealing with the following new subjects: Reduction of Traverses, Nature of the Differential Adjustment, and the Subject of Geodesy Treated From a New Point of View.

The traverse-theory is particularly interesting, as by it the ordinary surveyor's latitudes and departures on the plane are added together as latitudes and departures and converted by the simple application of Legendre's Theorem to true geodetic latitudes and longitudes. It is hoped that this will prove the means of linking up many of the old surveys with geodetic work.

The differential adjustment of observations is a very easy mathematical presentation, and it affords a rigorous method of keeping all the level-nets of this Survey up to date as from time to time they include new observations, and of showing the effects of the inclusion of these new observations. Similarly, in its effects on triangulation the old data are maintained. By this system it may be said that one net of adjustment can be added to another net or scheme by considering the connecting lines as differentials.

The treatise on geodesy, which has been delayed, but is now in page-proof form, possesses many unique features showing how the symbol

[1] See Bull. Nat. Res. Counc., 56: 41-46, Washington, D. C., 1926.

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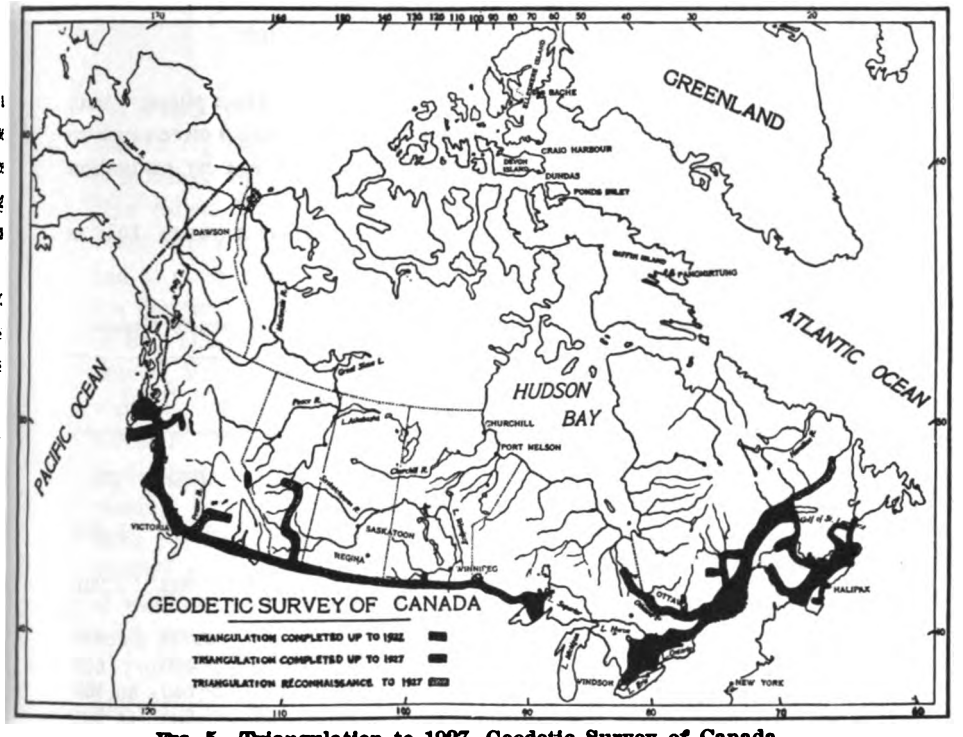

Fig. 5—Triangulation to 1927, Geodetic Survey of Canada.

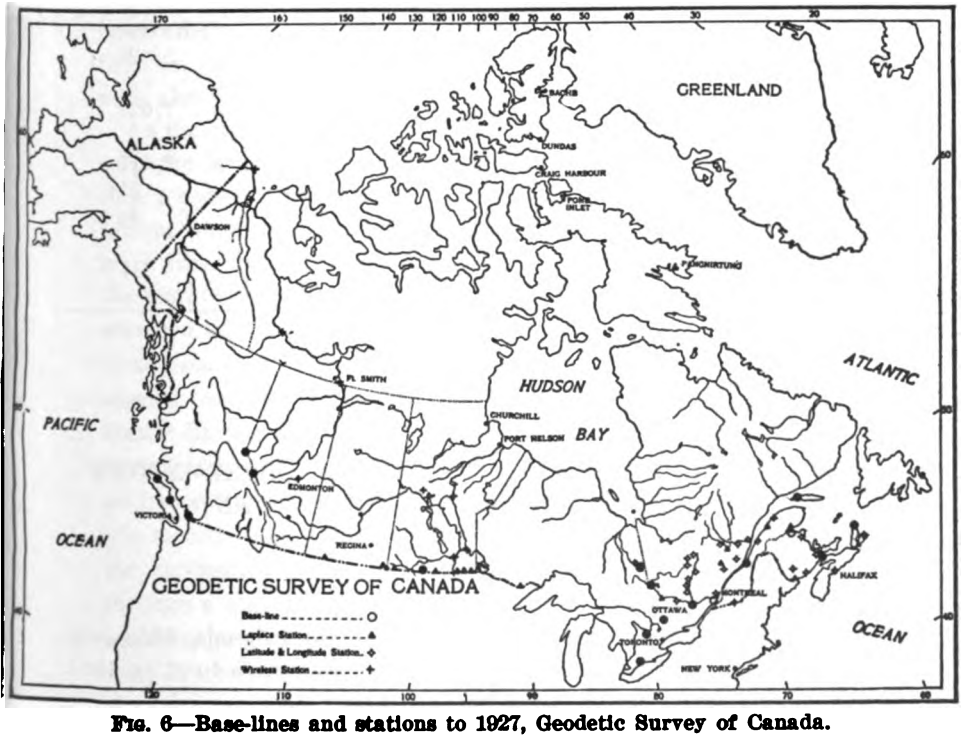

Fig. 6—Base-lines and stations to 1927, Geodetic Survey of Canada.

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"δ" has a magic relation between the ellipsoid and the sphere. Also, an attempt has been made to obtain rapidly converging power-series to express values which formerly were obtained by the lengthy evaluation of very unwieldy formulæ.

The progress of the field operations of the Survey through 1926 is summarized in Table 1.

TABLE 1—*Summary of Field Operations to 1926, Geodetic Survey of Canada*

Field operation	Prior to 1924		1924–1926		Total	
	Miles	*Km*	*Miles*	*Km*	*Miles*	*Km*
Completed first-order triangulation, length	3,575	5,753	1,441	2,319	5,016	8,072
Completed second-order triangulation, length	500	805	302	486	802	1,291
Reconnaissance; observing not yet started, length	482	776	731	1,209	1,233	1,985
First-order traverse, length	75	121	305	491	380	612
Precise leveling	21,134	34,011	1,526	2,456	22,660	36,468
Secondary leveling	9,261	14,904	47	76	9,308	14,980
	Number		*Number*		*Number*	
Fundamental bench-marks	.....		23		23	
Standard precise bench-marks	6,722		905		7,627	
Standard secondary bench-marks	2,891		26		2,917	
Base-lines	14		7		21*	
Laplace stations	18		16		34	
Astronomical stations, apart from Laplace stations	.....		7		7	

* Four of these are of second order.

Geodetic Survey of Canada,
Ottawa, Canada.

WORLD LONGITUDE-NET: U. S. NAVAL OBSERVATORY STATIONS AT WASHINGTON, D. C., AND SAN DIEGO, CALIFORNIA

F. B. LITTELL

The world longitude-campaign by the use of radio signals, which was originally proposed by General Ferrié in 1919, was carried out in 1926.

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For several years the matter had received the attention of a mixed commission representing the International Astronomical Union and the International Geodetic and Geophysical Union. In its final form the plan called for the simultaneous determination of the longitudes of twenty-three stations of the first order, representing thirteen countries, and of as many, or more, secondary stations (see Figure 1). Those of the first order comprise the original round-the-world-polygon composed of San Diego, Algiers, and Shanghai, and the stations at Washington, Ottawa, Vancouver, Greenwich, Edinburgh, Paris, Madrid, San Fernando, Naples, Genoa, Mogadiscio, Dehra Dun, Tokyo, Melbourne, Sydney, Adelaide, Wellington, Lembang, Manila, and Honolulu. It was desired to determine the longitudes of these stations with the highest precision possible, both as a contribution to our knowledge of longitudes, and as a basis for future studies relating to possible crustal movements of the Earth's surface. In order that there might be sufficient material even if weather or radio conditions should be adverse, the plan called for work extending over a period of two months.

The radio stations as originally planned were Annapolis, Bordeaux, and Honolulu, to which were added Bellevue, Eiffel Tower, Nauen, Saigon, and Malabar. Both long-wave and short-wave signals were used. The American stations sent out signals three times and the others usually twice a day. Nearly all the signals were of the rhythmic type, sixty-one ticks to the mean time minute, but the regular American time-signals were also used.

As the arrangements at Washington and San Diego were quite similar, only the latter need be described. There was a small observer's room, with a cement-lined clock-vault beneath. Immediately outside were two cement piers, one for the transit instrument and one for the meridian-mark lens, and 160 feet (48.8 meters) to the north was another pier for the meridian-mark. As these were constructed in 1923, they were well seasoned and in fine condition for use. The transit was mounted practically out in the open air. It was protected from the Sun's heat by a wooden covering, which was removed just before sunset each day. The transit having an aperture of three inches and a focal length of thirty-three inches was made by Prin, of Paris, in 1913. It was equipped with an impersonal self-registering transit-micrometer, driven by a small electric motor. The speed of the traveling wire is adjustable, according to the declination of the star, and the fine-motion is by hand, operating through a planetary gear. The device for recording on the chronograph was changed from a make-circuit to a break-circuit, thus eliminating a relay from the circuit, and making one less lag to investigate. The in-

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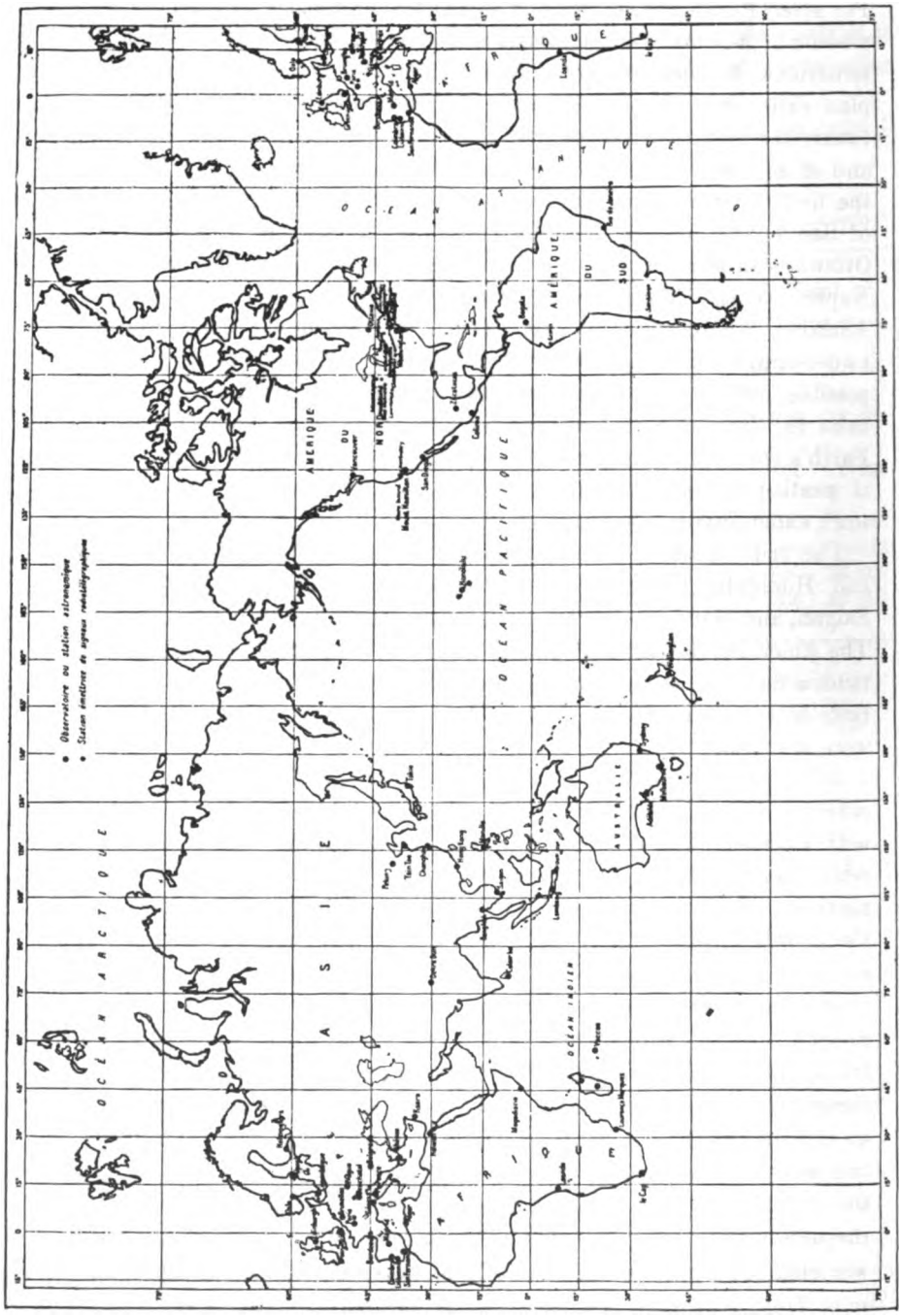

FIG. 1
(Observatories and astronomical stations taking part in the world longitude-campaign).

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strument is quickly reversible, and each star was observed direct and reversed at the same transit, thus eliminating immediately the effect of collimation-error and pivot-inequality.

The clock was a Riefler in an air-tight case in the clock-vault where the temperature was kept nearly constant by means of four small electric heating-units controlled by a kerosene-mercury-glass thermostat similar to the ones used at the Naval Observatory. During October the temperature-range was from 86° to 88° F, and during November, except for a few days when an electric connection was broken, the range was from 85° to 86° F. The clock performed excellently and the clock-correcting could be interpolated over intervals of a few days, with great security.

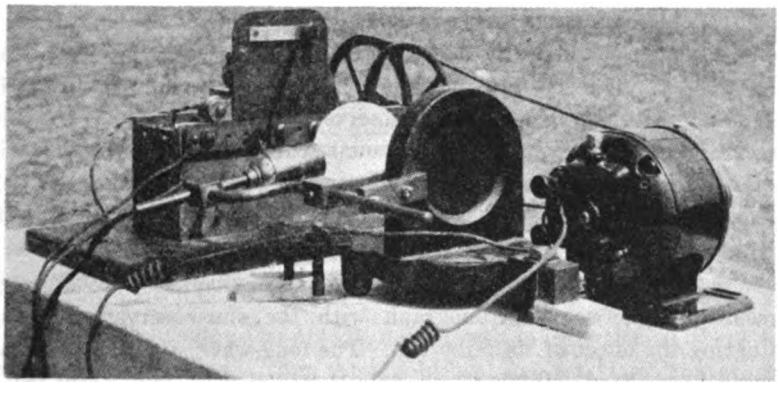

FIG. 2

Personal-equation machine on meridian-mark pier at San Diego, California.

This made it possible to utilize the radio signals on nights when no stars were observed.

The meridian-mark consisted of an artificial star collimated by a lens of 160-feet (48.8-meter) focus. As the Prin instrument moves very considerably in azimuth, such a mark was very necessary, even though the stars used were as near the zenith as practicable. A reading on the mark was taken near the time of each star-observation.

The level of the instrument was determined by a striding spirit-level. The vial was an excellent one by Pessler, and the value of a division was measured several times during the progress of the work by means of a level-trier, without removing the vial from the frame in which it was used. As a check on the level of the instrument, a nadir-observation over mercury was taken each night when possible. Even when there was no wind the nadir-images were almost always very poor, possibly due to vibrations caused by the surf, the location being very near the bay,

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although the ocean was several miles away. While the individual nadir-levels were very erratic there was no indication of any systematic difference between such levels and those obtained by the spirit-level.

A small personal-equation machine (see Figure 2) was mounted on the meridian-mark pier, and each observer measured his personal equation several times during the work. In the case of Mr. Hammond it was quite constant and small, the adopted correction being —0ˢ.004, while in the case of the writer it was variable, the adopted correction ranging from —0ˢ.036 at the beginning to —0ˢ.008 at the end. This change, which was corroborated by the comparison of the observed clock-corrections, may have been due to lack of recent experience in the use of the Prin transit. In the case of Mr. Watts, the Prin observer at Washington, the adopted equation was —0ˢ.007.

The probable error of a clock-correction from a single star was $\pm 0^s.016 \sec \delta$. This is quite materially less than in the 1913 to 1914 work, when the average for four observers was $\pm 0^s.028 \sec \delta$. The difference seems to be very largely accounted for by the improvement in the star-positions as given in the catalog of W. S. Eichelberger, recently published by the U. S. Naval Observatory, though some of it is due to improvements in the instrument and accessories.

The radio receiving-sets designed by Mr. Sollenberger were adapted to record on the same chronograph with the star-observations, thus eliminating the effect of its relay lag. The long-wave signals were most successfully received, Malabar and Saigon 9,000 miles and 8,000 miles away, respectively, being regularly recorded. In order to receive Annapolis, with which there was strong interference from a commercial station in Honolulu operating on exactly the same wave-length, a radio barrage was successfully employed. The combined lag of the receiving set and of one intervening relay was measured and corrected for. The corrections at San Diego ranged from —0ˢ.019 to —0ˢ.028. At Washington they were larger, but well determined. The correction was a function of the current-strength from the radio set, and this was recorded for each observation.

Fog and condensation interfered with observing stars at San Diego in the latter part of the night during October, but sufficient work for a time-sight was obtained on fifty-four out of the sixty-one nights, and on twenty-six of these nights two clock-corrections were obtained. At Washington time-sights were secured on forty-three nights.

The following preliminary results have been obtained. The Greenwich results are based on data kindly furnished by the Astronomer Royal for England, those for Paris are based on data in the Bulletin of the B. I. H.,

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Vol. II, No. 32. In the Washington-San Diego longitude, nine different radio signals were used, and there seems to be very little difference either in accuracy or in the end result, as to whether the signal be long-wave or short-wave, American or rhythmic style, day or night.

Preliminary Results

	h	m	s	s
Washington-San Diego, 1926, radio	2	40	32,641	±0.002
Washington-Greenwich, 1926, radio	5	08	15.753	± .002
" " 1913 to 1914, radio	5	08	15.721	± .014
" " 1866 to 1892, cable	5	08	15.78	± .050
San Diego-Greenwich, 1926, radio	7	48	48.390	± .002
Washington-Paris, 1926, radio	5	17	36.659	± .003
" " 1913 to 1914, radio	5	17	36.653	± .003

Velocity of Radio Transmission

Washington-San Diego	179,000 ± 14,000	miles per second
Washington-Greenwich	139,000 ± 5,000	miles per second
Washington-Paris	112,000 ± 8,000	miles per second
Washington-Paris, 1913 to 1914	179,000 ± 12,000	miles per second

In the Washington-Greenwich determination of velocity there were used two sets of signals from Annapolis and one set from Bordeaux, all recorded automatically, and all reduced by direct readings of the times of the signals except the Bordeaux signal received at Greenwich, which was reduced by an estimation of coincidence times. This difference in the method of reduction may be the cause of the low value obtained for the velocity. The transmission-times are quite accordant, and a systematic error of about one one-hundreth second would be sufficient to account for the low velocity.

In the Washington-Paris determination of velocity, there were three sets of signals from Annapolis and two sets from Bordeaux available, all recorded automatically. The resulting velocity seems to be much too small. When the transmission-times from an individual night's work are plotted, they show marked variation with the time of a somewhat periodical nature.

U. S. Naval Observatory,
Washington, D. C.

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A STUDY OF THE VARIATION OF MEAN SEA-LEVEL FROM A LEVEL SURFACE

HENRY G. AVERS

It was stated at a meeting of this Section two years ago that the first-order leveling seemed to be developing the fact that the planes of mean sea-level at adjacent tidal stations along the same coast are not, necessarily, in the same level surface.

This condition was first brought to our attention when the tidal stations at Fort Hamilton, New York, and Portland, Maine, were connected by a line of first-order leveling. The results of the leveling showed the plane of mean sea-level at Portland to be 169 millimeters higher than the same plane at Fort Hamilton. Similarly, on the Pacific Coast the leveling showed that the plane of mean sea-level at Vancouver, B. C., was 103 millimeters higher than the same plane at Seattle, Washington. In each case, mean sea-level at the northern station was the higher.

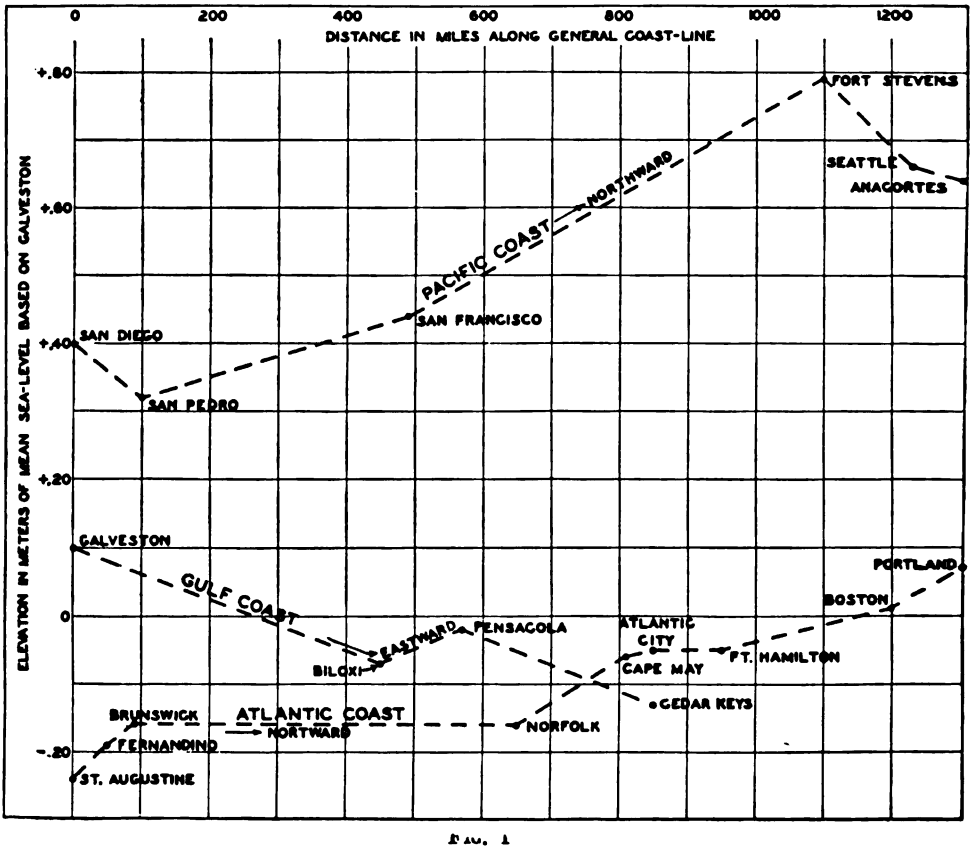

FIG. 1

Graphs showing adjusted elevation of the plane of mean sea-level at each tidal station above the same plane at Galveston, Texas.

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These differences are about three times as large as those which could reasonably be attributed to the systematic or accidental errors in the leveling and a study has been made to determine if, in general, there is a slope in the mean sea-level surface.

For the purpose of this study a special adjustment of the first-order level-net has been made. Before adjusting the net, certain level-lines were omitted which had received very low weights in the previous general adjustments. These lines included all the leveling run by the U. S. Coast and Geodetic Survey previous to 1899 and some of the leveling run by the U. S. Geological Survey previous to 1905. The closing errors of the circuits of which these lines formed a part also showed that they were weaker than the more modern lines of leveling. The total length of the leveling used in the adjustment was about 40,000 miles.

In the adjustment the entire net was allowed to swing free on one mean sea-level connection, that at Galveston, Texas. There are 104 circuits in the net and the adjustment was carried through by the method of conditions, each circuit-closure requiring an equation. There were no conditions other than the closing errors of the circuits.

The adjusted elevation of the plane of mean sea-level at each tidal station above the same plane at Galveston, Texas, is shown in Figure 1.

Starting at Galveston, Texas, and proceeding eastward along the coast of the Gulf of Mexico the planes of mean sea-level at Biloxi, Mississippi, at Pensacola and Cedar Keys, Florida, are respectively 0.07 meter, 0.02 meter, and 0.13 meter lower than the plane of mean sea-level at Galveston.

Starting at St. Augustine, Florida, where mean sea-level is 0.24 meter lower than at Galveston, and proceeding northward along the coast of the Atlantic Ocean the elevation of the plane of mean sea-level at the following places is, Fernandina, Florida —0.19 meter; Brunswick, Georgia, —0.16 meter; Norfolk, Virginia, —0.16 meter; Cape May, New Jersey, —0.06 meter; Atlantic City, New Jersey, —0.05 meter; Ft. Hamilton, New York, —0.05 meter; Boston, Massachusetts, +0.01 meter; and Portland, Maine, +0.07 meter.

On the coast of the Pacific Ocean, starting at San Diego, California, where mean sea-level is 0.40 meter higher than at Galveston and proceeding northward the elevation of mean sea-level at the following places is, San Pedro, California, +0.32 meter; San Francisco, California, +0.44 meter; Ft. Stevens, Oregon, +0.79 meter; Seattle, Washington, +0.66 meter; and Anacortes, Washington, +0.64 meter.

The foregoing values would indicate that along the coast of the Gulf of Mexico there is a general slope downward in the mean sea-level sur-

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face from west to east. Along the coasts of the Atlantic Ocean and the Pacific Ocean a general slope upward of the mean sea-level surface from south to north is indicated.

Comparison of mean sea-level on the Pacific Ocean with mean sea-level on the Atlantic Ocean shows that at San Diego it is 0.59 meter above Fernandina, Florida; at San Francisco it is 0.49 meter above Atlantic City; and at Seattle it is 0.59 meter above Portland, Maine. In each case the leveling indicates that mean sea-level on the Pacific Ocean is higher than on the Atlantic Ocean. This result agrees in sign with that shown by the leveling across the Isthmus of Panama where it was found that mean sea-level on the Pacific Ocean is 0.583 foot (0.178 meter) higher than on the Atlantic Ocean for that locality.

The values given for the differences in level between the various planes of mean sea-level are from the results of the leveling on the basis that the tidal observations determine the actual mean sea-level surface. All of the leveling involved in the adjustment is of the first-order and of such accuracy that, on an average, a correction of about 0.15 millimeter per kilometer is necessary to close the circuits. It is believed, therefore, that the differences in level shown by the adjustment are real differences and that they are not due to any peculiarities in the leveling.

U. S. Coast and Geodetic Survey,
Washington, D. C.

WORLD LONGITUDE COMPUTATIONS AND ISOSTATIC REDUCTIONS OF GRAVITY AT SEA

C. H. Swick

Two stations of the world longitude-net, Honolulu and Manila, were occupied by observers of the U. S. Coast and Geodetic Survey. Satisfactory observations were obtained at both stations, although at Manila there was some delay in getting started owing to difficulties with the radio apparatus. An interesting feature of the work at both stations was the use of the gravity-pendulum in place of an accurate astronomical clock.

A precision time-piece was needed in this work because the various radio signals came in at different times of day and night and it was obviously impossible to make an independent time-determination for each signal received. Instead, a set of star-observations was made on each clear night, and the precise rate of the chronometer, during each interval between the mean epoch of these observations and the time of the radio signals, was determined by means of the gravity-pendulum.

At Honolulu, a very good check on the accuracy of this method for

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carrying time was obtained in the following manner. It happened that one set of signals emitted each day by the Honolulu radio station came about midway between the time-observations on the preceding and the following nights. It was possible, therefore, in many cases to obtain the local sidereal time of this particular set of signals both by computing ahead from the preceding time-determination and backward from the following one. In several instances the discrepancy thus obtained was less than one one-hundredth of a second of time, and the maximum only slightly greater than two one-hundredths. This indicates not only that the gravity-pendulum is a very accurate time-piece but also that the time-observations themselves are remarkably consistent.

The chief objection to this use of the gravity-pendulum is the rather excessive amount of labor involved both in the field observations and in the office computations. For example, at Honolulu the pendulums were kept going almost continuously for more than fifty days and several extra observations were made each day to compare the pendulum with the chronometer at the times of the different radio signals. Altogether the observations and computations of the pendulum part alone amounted to as much as would be required at twenty-five or thirty ordinary stations.

The final results of the world longitude-work will not become available until all the differences which were determined last October and November have been adjusted into one great net around the world. It has been partly arranged that the U. S. Coast and Geodetic Survey shall have at least the Pacific Ocean part of this net to adjust. If one looks at a map on which the stations are plotted [1] this looks like a simple task; but if one considers that at San Diego alone the Naval Observatory determined the local sidereal time of 650 different sets of signals and that each of these signals gives a longitude-difference with every station recording the same one, the work involved in getting all the data coordinated begins to look formidable.

In December Dr. Meinesz arrived at Java and thus completed his circumnavigation of the globe in a submarine of the Dutch Navy. His belt of gravity-determinations at sea now extends entirely around the world. In February, after a brief rest, he made an additional series of determinations across the edge of the continental shelf south and west of Java. This trip, by the way, came near to being disastrous as something went wrong with the machinery and the ship submerged to a depth of eighty meters before an adjustment could be made. As this was twenty meters beyond the maximum depth for the submarine the

[1] See map given in connection with the preceding paper in this Bulletin by F. B. Littell.

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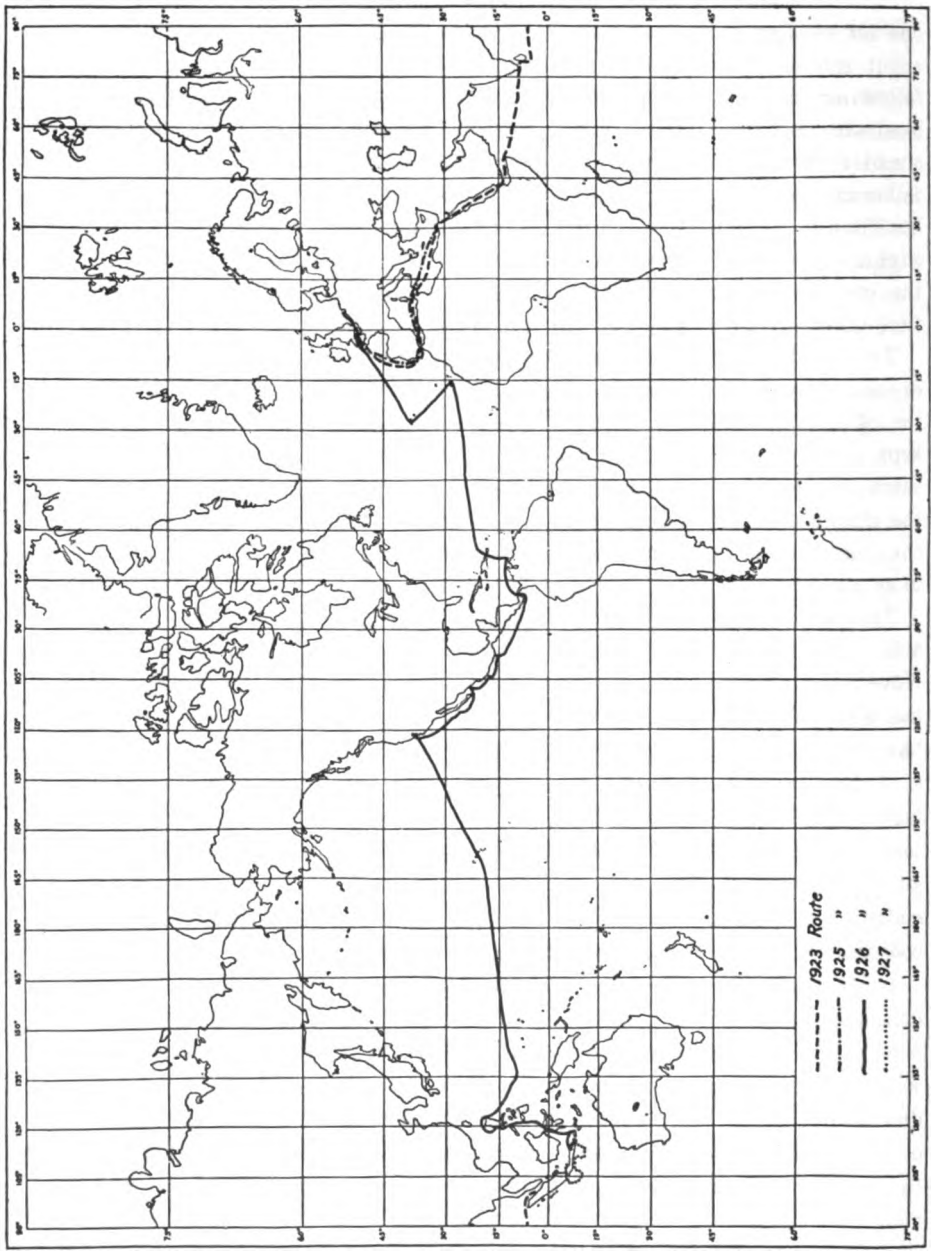

FIG. 1

Routes followed by the Dutch submarine on which Dr. F. A. Vening Meinesz made his gravity-determinations at sea.

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danger of collapse was very great, the pressure at this depth amounting to more than eight tons per square foot.

On his trip across the Atlantic and as far as Honolulu in the Pacific, Dr. Meinesz was able to make preliminary computations of his observations for many of the stations; these he forwarded to the U. S. Coast and Geodetic Survey whenever he had an opportunity. Beyond Honolulu the extreme heat and other hardships of the trip affected Dr. Meinesz' health to such an extent that he was unable to make the computations and it was only with much difficulty that he kept up the observations.

Dr. Meinesz returned to Holland in March and within a few weeks he will probably send us the results for the rest of his stations. There are about one hundred stations for which he has not yet sent the data. We hope to complete the reductions within a short time after the data become available, perhaps in time to permit Major Bowie to give a preliminary report at the Prague meeting. It is expected that the complete report of the reductions will be published by Holland as was done for the thirty-one stations [2] of the first trip in 1923.

The isostatic reductions have already been made for fifty-six stations between Holland and Honolulu. Except for two large negative anomalies near Porto Rico, nothing about the results warrants special comment except the tendency of the anomalies to be positive, especially over the deep water. Of the twenty-five stations in the Atlantic which have been reduced, all have positive anomalies except the two just mentioned. In the Caribbean Sea there are an equal number of positive and negative anomalies, but in the Pacific the tendency is strongly positive again, only two out of twenty-five stations having negative anomalies. The average isostatic anomaly for the fifty-six stations is +0.026 dyne.

In studying over these anomalies, Major Bowie and I have come to the conclusion that positive anomalies over the oceans are due to a large extent to the depression of the geoid over these areas and to the fact that the gravity-formula is based on determinations at land stations alone, at many of which the geoid surface is considerably above the spheroid. If it were possible to apply an elevation-correction to reduce each observed value of gravity to the spheriod, the formula derived from these values would undoubtedly have quite different constants from those in our present formula, and the anomalies over the oceans would then have very nearly normal values.

A computation of the depression of the geoid in the Atlantic, off the

[2] Isostatic reductions by the U. S. Coast and Geodetic Survey of the results of the pendulum-observations at sea made in 1923 between Holland and Java. Publication of the Dutch Geodetic Committee, Delft, 1926.

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coast of South Carolina, showed that at a point 525 miles east of Charleston the geoid is more than twenty-four meters lower in relation to the spheroid than at Charleston. A correction for even this amount of depression would change the anomalies by 0.008 dyne. In the middle of the Atlantic the depression of the geoid is undoubtedly greater than at the point computed.

U. S. Coast and Geodetic Survey,
Washington, D. C.

LOOP-CLOSURES RESULTING FROM THE READJUSTMENT OF THE FIRST-ORDER TRIANGULATION IN THE WESTERN PART OF THE UNITED STATES

O. S. Adams

At the meeting of this section of the Union last year a partial report on the readjustment of the first-order triangulation in the western part of the United States was given. The work of the adjustment has now been advanced to the point at which some interesting and important results can be given.

At the time of the report last year two sections remained to be observed. These were the western end of the 49th parallel and the arc in southern California and Nevada joining the coast arc to the one extending from the 39th parallel in western Utah southward to the Mexican boundary. The field work on these sections was completed in due time and the office work of the figure-adjustment was made as quickly as possible. It was the desire of the Coast and Geodetic Survey to finish all the work of the preliminary adjustments at as early a date as possible so that the loop-closures could be computed and the readjustment of these closures could be made so as to fix the final positions in the junction-figures.

FIG. 1

Loop-closures in feet with number of miles in loop and approximate proportional part of length of loop that closure represents.

Figure 1 with the loop-closures shows some surprising results regarding

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the accuracy of triangulation when length and azimuth-control are introduced into the adjustment. There are only two loop-closures greater than one part in 200,000 and the largest closure in the whole scheme is only one part in 162,000.

The mean of all the closures is approximately one part in 450,000. The closure around the entire outer boundary is thirty-three feet in a distance of 5,300 miles or approximately one part in 842,000. In the whole network there are between twelve and thirteen thousand miles of triangulation, or enough to reach half way around the Earth at the equator.

The adjustment of these closures has been finished and the final position of a station in each junction-figure has thus been determined. Since an azimuth in each of these junctions is fixed by the Laplace azimuth-observations, it is now possible to compute the positions of all of the stations in each junction-figure. The exact latitude and longitude of these control-stations in the junction-figures are of no especial interest in themselves, but the change in these positions from previously adjusted values is of interest and is shown in Figure 2. It will be seen that all of the west-coast stations have been moved south and east approximately one second of arc in each direction. At the northwest corner the change is —1."056 in latitude and —1."374 in longitude. This junction will furnish the data that is to be carried northward through

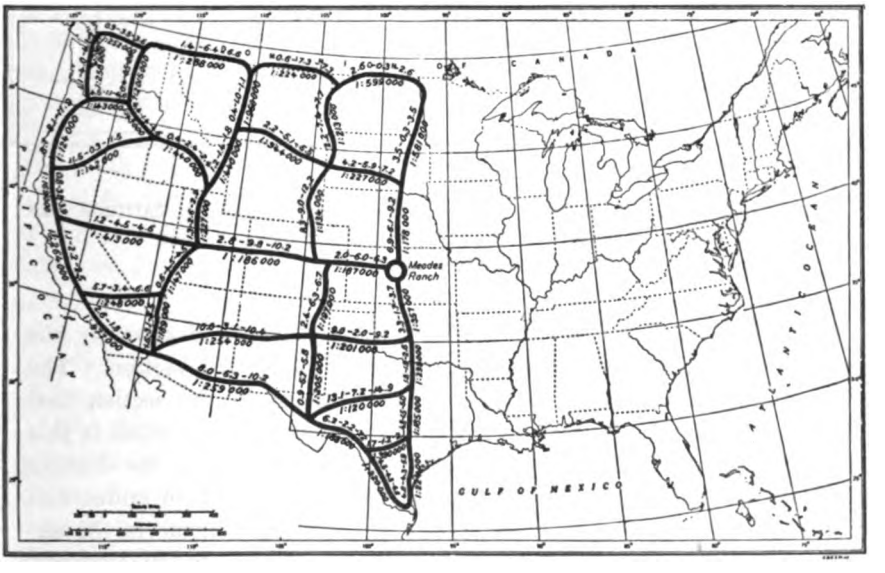

FIG. 2

Readjustment changes in latitude and longitude of points previously adjusted.

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western Canada to our triangulation in southeast Alaska. These data have already been tabulated and a copy has been sent to the Geodetic Survey of Canada so that that organization may be able to use this control in the computation of its work which connects directly with the first-order work in Alaska. It is expected that the computations in Alaska will soon be put on the North American Datum of 1927.

The adjustment of the loop-closures distributes these closures among the various sections in such manner as to do the least possible violence to the various parts of the general scheme. Figure 3 shows in feet, first

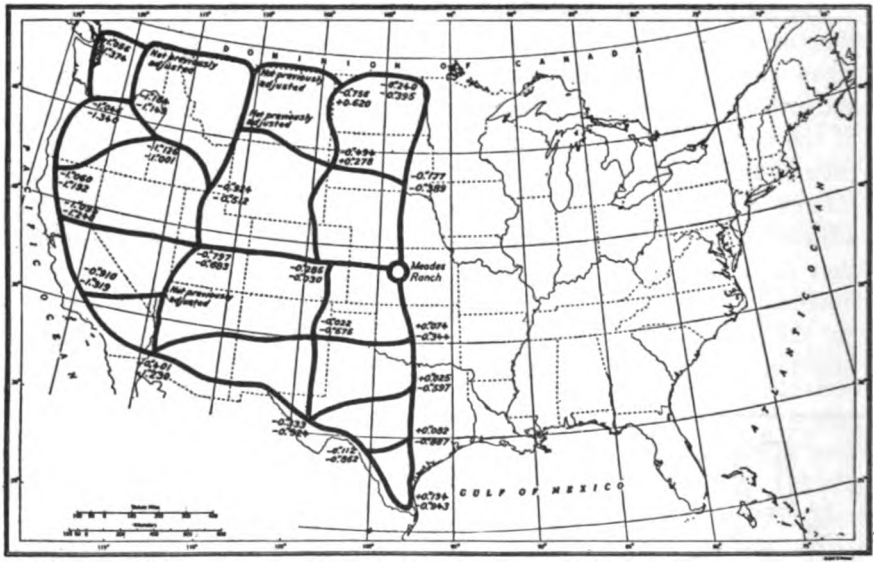

FIG. 3

Closures in feet to be absorbed by the sections: (1) Closure in latitude, (2) closure in longitude, (3) total closure in distance, and (4) approximate proportional part.

the amount that must be absorbed by the latitude, and secondly the amount by the longitude, and the total closure of the section. The approximate proportional part of the total length of the section that this closure represents is also given in each case. In no section is this closure greater than one part in 120,000 and the majority of the closures are near one part in 200,000 or better. This means that no undue violence will have to be done to any parts of the entire scheme in the adjustment of the sections to absorb these still outstanding discrepancies.

It will now be the task to add the conditions for closure in latitude and longitude to the various sections of the network and, in this way, to

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adjust the whole into one continuous framework. In this way, part of the closure of each loop is put in each section and no section will have to absorb an undue amount. By the former method of piecemeal adjustment, any new section closing a loop was required to absorb all of the closure of the loop and hence oftentimes severe violence was done to arcs of excellent observational data. The fact that the orientation has been maintained throughout by Laplace azimuth-observations has obviated one of the weak elements in triangulation, and this fact has contributed greatly to the excellent closures that we have found in our work of adjustment.

U. S. Coast and Geodetic Survey,
Washington, D. C.

A PROGRESS REPORT ON THE GEODETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY

C. V. Hodgson

Since the last meeting of the Section one major arc of first-order triangulation has been completed, a minor arc has been begun and completed, and a beginning has been made upon another major arc.

The major arc completed was the west end of the 49th parallel, an unusually difficult piece of work; the stations were so inaccessible that five observing parties were used in order to finish the work before the glaciers below the stations should become dangerous. Even with that number of parties, smoke from forest-fires again so delayed the observing that the stations were finished only with the greatest difficulty and with frequent risk of serious injury to the observers and their assistants.

The minor arc completed extended from Las Vegas, Nevada, across the south end of Death Valley westwardly to a junction with the Pacific Coast triangulation at about the 36th parallel. It serves the two-fold purpose of dividing up a large area devoid of first-order control and will also, we hope, help to localize some of the large apparent changes in geographic position of points in the Pacific Coast triangulation. Both this project and the one completing the 49th parallel triangulation were finished in time to be included in the adjustment described by Dr. Adams.

The third arc was east of the 98th meridian where we have an area of about 200,000 square miles, including all of Iowa and parts of the adjacent States, with no first-order horizontal control points in it. A start was made last year toward the development of that area by observing for about 100 miles along a north-and-south arc in northern Iowa, which will eventually extend from northern Minnesota to the Gulf. At the same time about 200 miles of first-order traverse were run in Wisconsin

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as a part of the same scheme. During the coming summer we hope to complete the part of the scheme lying in Minnesota.

Passing now for a moment to the future, several belts of triangulation are needed to develop the area east of the 98th meridian to a point where a study can be made of the errors of position similar to that described by Dr. Adams. About 5,000 miles of triangulation and traverse will be required for this initial development of the eastern half of the country which will require about $375,000 for the field and extra office work. At the present rate of appropriation for geodetic work it will require seven or eight years to complete the horizontal control outlined. From a purely scientific standpoint we might be content to let the mills of the gods grind on at their present rate, but from an economic standpoint that rate is entirely too slow.

Several short lines of first-order leveling were run during the year but none had any unusual importance in the development of the system of precise levels. The principal lines were in South Dakota, Colorado (two projects), and California. The appropriation of $10,000 for geodetic survey in regions subject to seismic disturbances was spent entirely on leveling in California and, while the results thus far obtained are not startling they will serve as an excellent foundation for future investigations.

It is always interesting to examine a progress map and to do "paper reconnaissance" on it. In Colorado and Utah there is an immense area without cross lines of levels. A line across Utah will, we hope, be completed during the coming summer, and our plans for next year include a line of levels from Albuquerque to Pueblo, which will subdivide another large blank area on the map. Other lines of importance will be run as rapidly as funds permit. Thus the level-net grows in intricacy of design; turning back the years and looking at the level-net of 1916 we can see that some progress has been made even though it is not as rapid as we should like to see.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SUGGESTIONS FOR THE IMPROVEMENT OF PENDULUM OBSERVATIONS

C. A. Heiland

In the location of mineral deposits or geological subsurface structures by means of gravity-measurements, the Eötvös torsion balance has hitherto been used almost exclusively. Pendulum measurements have been but little used in the solution of such problems and then chiefly

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when the problem was one of surveying large buried tectonic units, extending over a considerable area. What has hampered the use of the pendulum measurements in most cases has apparently been the time required to make them, apart from the fact that the gravity anomalies produced by most types of subsurfaced structures do not greatly exceed the errors of the results.

The comparatively large amount of time necessary for pendulum observations is, as is generally known, due to the fact that the oscillations of the pendulums must be compared with those of an astronomic clock carried around in the field; the rate of the clock in turn must be checked at each station, either by astronomic time-determinations or by the reception of radio time-signals. In other words, it is necessary to spend at each field station a time at least as long as the interval between two consecutive time-determinations, that is, about twenty-four hours.

In order to reduce this time, it has been suggested (A. Berroth, Zeitschrift für Geophysik, 1927, Heft I) that the astronomic clock be left permanently at a central station and connected by wires to the flash-box of the various field stations. With this arrangement, it is not necessary to wait at the field stations for the time-signals; one field station may then be finished in about four hours. However, Berroth found that this advantage in time was compensated to a considerable extent by the time wasted in the repair of the wiring between the central station and the field stations. He, therefore, suggested the broadcasting by radio of the beats of the astronomic clock, the reception of these signals at the field stations and their conversion into beats of the flash-box.

Unquestionably a central arrangement of the clock would save considerable time. Moreover, the accuracy of the results may be expected to increase somewhat, since the rate of the astronomic clock, when set up permanently at some one place, will probably be more nearly constant than it would be when carried around in the field.

There remains, however, one disadvantage, because the results are still affected by any faults in the behavior of the clock between two time-signals; in other words, it would not be possible to find out whether within twenty-four hours the astronomic clock showed, for instance, a sudden change of its rate instead of a continuous variation. Moreover, another source of error is the mechanical contact made in the astronomic clock to set the flash-box to work; the operation of this calls for the use of electromagnets and springs and, therefore, involves also a time-lag, which can not be expected to be always constant.

I therefore offer for discussion the following suggestion, one aim of which is first to dispense entirely with astronomic time-determinations

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when radio time-signals are received. Second, the proposed method does away with the flash-boxes and, third, it does away with the visual observations of the moment of coincidence. It, therefore, may be expected to improve the accuracy of the results.

It is possible to make the measurements at two stations exactly simultaneous, so that any variations of the rate of the central chronometer during the time of observation are eliminated.[1]

If we denote by T the time of oscillation of the central chronometer, by T_o its value when observations are made at the central station having the gravity g_o, by $T_,$ and $T_{,,}$ its values at the time when measurements are made at the field stations having the respective values of gravity $g_,$ and $g_{,,}$, and if we let m (with corresponding subscripts) denote the factor $\frac{n}{2n \pm 1}$ in the coincidence formula, and l the length of the pendulum we have

$$\frac{g_o}{\pi^2} = \frac{l}{m^2_o T^2_o}$$

$$\frac{g_,}{\pi^2} = \frac{l}{m^2_, T^2_,}$$

$$\frac{g_{,,}}{\pi^2} = \frac{l}{m^2_{,,} T^2_,}$$

whence

$$\frac{g_,}{g_{,,}} = \frac{m^2_{,,} T^2_{,,}}{m^2_, T^2_,}$$

There are two possible ways of eliminating $T^2_{,,}$ and $T^2_{,,}$ in this equation: (1) by observing with a single pendulum-apparatus at two stations and keeping T constant during the time required for both observations; (2) by making the measurements at the two stations exactly *simultaneous* with *two sets of apparatus* (any variations of T would thus be eliminated). Since the first method is practically unattainable, we choose the second one.

The constant difference of the two sets of pendulum apparatus 1 and 2 employed may be determined by simultaneous standardization at the

[1] The advantage of making simultaneous observations at two field stations may have occurred to others, but no methods have been published which could be used for this purpose.

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central station. For (omitting now the subscripts of T for the case of simultaneous observations) we have

$$\frac{l_1}{m^2_o T^2} = g_o = \frac{l_2}{M^2_o T_2}$$

where M is the factor m for the instrument No. 2

$$m^2_o = M^2_o$$

or putting

$$\frac{l_1}{l_2} = q$$

$$m^2_o = M^2_o q$$

Then

$$\frac{g_,}{\pi^2} = \frac{l_1}{m^2 T^2}$$

and

$$\frac{g_{,,}}{\pi^2} = \frac{l_2}{M^2 T^2}$$

T cancels out, giving

$$\frac{g_,}{g_{,,}} = q \frac{M^2_{,,}}{m^2_,}$$

Putting

$$M^2 = M^2_o a = \frac{m^2_o}{q} a \text{ and } m^2_, = m^2_o b,$$

we get

$$\frac{g_,}{g_{,,}} = \frac{a}{b}.$$

This simple relation expresses the ratio of the values of gravity at two neighboring stations which have been determined simultaneously.

The question now is, how to synchronize the observations at the two neighboring stations, or, strictly speaking, how to arrange matters so that exactly the same beats of the central clock may be used at both stations for comparison with the pendulums.

The proposed mechanism is as follows: At a central station we place, not the usual astronomic clock, but a pendulum apparatus, the invariable pendulum of which is made to swing continually in a vacuum. In front of the pendulum mirror in the receiver there is a lens instead of a plain

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glass, at the focus of which a diaphragm is placed illuminated by a strong electric light. A beam of light, therefore, goes through the diaphragm, then through the lens in the receiver, is reflected by the pendulum mirror and passes through the lens again. At the focus of the lens there is also another diaphragm, behind which is placed a photoelectric cell, the position of which is so adjusted that the reflected beam of light just hits

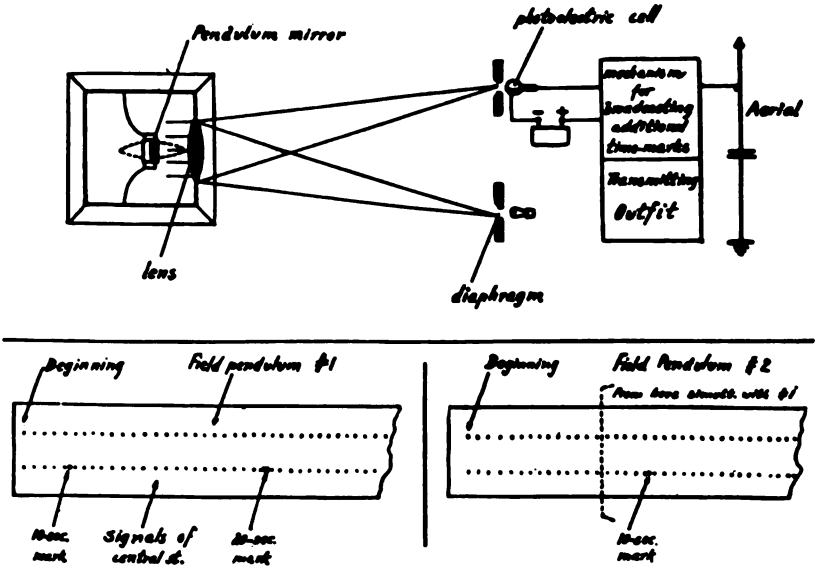

FIG. 1

Schematic diagram of apparatus for proposed central transmitting-station and of records at receiving field-station (started simultaneously within one minute).

this second diaphragm if the pendulum is in perfect rest or if it passes through this zero-position while swinging. Every exposure of the photoelectric cell produces an impulse of an electric current, which in turn acts upon the circuit of a radio transmitting-set. In other words, the radio set at the central station transmits a dot whenever the pendulum passes its zero-position. The two field stations at which the observations are to be made simultaneously are each equipped with a receiving outfit. The variations of the arriving wireless energy are there converted into fluctuations of an electric source of light, and the signals of the central pendulum are recorded photographically on the same sheet as the oscillations of the field pendulum on each station.

In order to use exactly the same beats of the central pendulum for the comparison with the pendula at both stations, the signals must be marked

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in some way. This is done by the arrangement described in the next paragraph.

The circuit, which is closed whenever the photoelectric cell is exposed, also operates an electromagnet, which moves a dial in a counting mechanism. This mechanism is in turn connected with another mechanical arrangement which effects the broadcasting of six different special signals, consisting of dots and dashes. The counting mechanism brings it about that when twenty dots are transmitted, i. e., after ten seconds, the first special signal is broadcasted. After twenty seconds, there follows the second special signal, and so on. Since, in other words, sets of sixty seconds each can be readily distinguished on the photographic sheet, it is only necessary to start the records on each field station within one minute simultaneously. Any ordinary watch furnishes this accuracy. In reading the results from the photographic sheets, exactly the same beats of the central pendulum can be used for comparison with the field pendulums.

In applying the preceding method, it is no longer necessary to compare the central clock with absolute time-determinations or with radio time-signals. I believe, therefore, that it should be possible in the future to occupy with the proposed method about four field stations a day, including the establishment and dismantling of the stations.

Colorado School of Mines,
Golden, Colorado.

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SECTION OF SEISMOLOGY

(Washington, D. C., April 29, 1927)

REPORTS OF PROGRESS IN SEISMOLOGICAL WORK IN THE UNITED STATES

A—CARNEGIE INSTITUTION OF WASHINGTON

ARTHUR L. DAY

The activity of the Carnegie Institution of Washington in the field of seismology in 1926 may be reviewed briefly somewhat as follows:

One major task, jointly elaborated at the outset between the Institution and the U. S. Coast and Geodetic Survey, contemplated fixing the position both in horizontal and vertical dimensions of significant landmarks throughout the entire zone of earth-movement in California. The obvious purpose, which has often been alluded to before, was twofold, (1) to fix with precision the actual displacements occurring during earthquakes, (2) the much more novel, and, eventually, perhaps more useful, purpose of attempting to evaluate indications of accumulating stress or "creep."

"The pursuit of this object has made necessary a new primary triangulation extending southward from Ukiah to the Mexican boundary, and east and west across the State to suitable points beyond the Sierra Nevada Range which is believed to be nearly free from movement. This triangulation is now nearly completed, north and south, and three lines have been finished in the east-west direction, namely, at San Francisco Bay, San Luis Obispo, and the Mexican boundary.

"For the detection of vertical movements lines of precise leveling have been undertaken in the southern portion of the State, chiefly with reference to known fault-zones. The leveling is still in progress. Eventually it is hoped to extend it over substantially all of the region covered by the recent triangulation."

The second major task which the Institution confronted was an adequate, detailed study of the geology of those portions of the west coast region in which the movements more commonly occur. This is a task of very considerable dimensions covering a detailed geological examination of the southern two-thirds of the State of California. It can therefore only proceed slowly, in collaboration with the U. S. Geological Survey and the geological departments of the universities and technical schools of central and southern California. The first published report of this work was prepared by Dr. Levi F. Noble, of the U. S. Geological Survey, and contains detailed studies of portions of the master-fault of

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California, the San Andreas Rift. This report is printed in the Annual Report of the Advisory Committee in Seismology of the Carnegie Institution of Washington for 1926. Several years are expected to be occupied with these geological studies.

The third item on our program has been the primary responsibility of the Carnegie Institution of Washington alone, namely, the development of suitable instruments for the study and evaluation of local earth-movements in the region under investigation and the erection of suitably located stations for their installation. The Wood-Anderson seismograph has been devised for this purpose and the two horizontal components have now been in service for three years or more. Instruments of this type are now being installed in the new central station in Pasadena and in subordinate stations at Riverside, at La Jolla, at Santa Barbara, and at the Mt. Wilson Observatory. Other stations are also under consideration. Several designs of vertical-component instruments have been considered and three different types have been set up at different times, but this phase of the problem is not yet completely solved. With this group of stations in southern California there will probably be affiliated a second group about San Francisco Bay in charge of Professor Byerly, of the University of California. The cost of these stations has been contributed by citizens of San Francisco, and instruments of the same type as those used in the south are in process of manufacture. Probably another year will see this northern group of stations in successful operation as well.

It is a particular pleasure and privilege to announce that the central laboratory building in Pasadena, built for this purpose by the California Institute of Technology, has just been completed and the apparatus is at this moment being installed in it. It is a beautiful building for the purpose, well located, simple in architecture, but with abundant space for the investigations to be undertaken in it. Several piers erected upon the underlying granite afford the best of facilities for the transmission of earth-vibrations to the instruments and two tunnels leading into the granite hillside provide opportunity for tilt-measurements or other experimental studies. This laboratory is to be in charge of Mr. Harry O. Wood, who has conducted the work in Pasadena since its inception.

Of the problems to be taken up in this laboratory it is perhaps too early to give any extended account. Its first concern is obviously to develop a vertical-component instrument which shall be equally as competent for the purpose as the Wood-Anderson horizontal-component instrument. The second is almost equally obvious, namely, to provide for identical minute-to-minute time-signals for all of the stations which

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are to participate in this investigation. This year is likely to be fully occupied with these two problems alone.

Meanwhile the development of a driving mechanism for the chronographs, which receive the seismometer-records, is now practically completed. A beautiful electric mechanism driven from a tuning-fork or vibrating reed with power derived from a storage battery has been devised which provides a uniform speed of rotation with the minimum expenditure of power. The synchronous motors operate gear-work which is designed to run in oil and to give a speed of rotation of the recording drums of 60, 30, 15, or 7.5 mm per minute. Under favorable conditions an accuracy of one part in a hundred thousand has been attained.

These devices are likely to prove of the greatest convenience in all chronograph-work. They appear to be thoroughly trustworthy in use and inexpensive to operate. They have been offered for patent and will presently be described in print.

The Committee has continued to administer during the past year the grant of $5,000 provided by the Carnegie Corporation of New York in aid of seismological publication. Twenty-four reports of recent seismologic research, including the full description and theory of the torsion seismometer by Anderson and Wood, have been printed in the Bulletin of the Seismological Society of America, either wholly or partly at the expense of this fund, which has been of the greatest service to seismology in its hour of need. Amount expended $3,358.96. The available balance of the fund on July 1, 1926, was only $1,641.04. It will presently be exhausted and it is understood that a renewal of the grant is not to be expected.

Advisory Committee in Seismology,
Carnegie Institution of Washington,
Washington, D. C.

B—JESUIT SEISMOLOGICAL ASSOCIATION

JAMES B. MACELWANE, S. J.

The Jesuit Seismological Association, organized in the summer of 1925, is composed of twelve seismographic stations built and equipped by Jesuit universities and colleges in the United States. These are Canisius College, Buffalo, New York; Loyola University, Chicago, Illinois; St. Xavier College, Cincinnati, Ohio; Regis College, Denver, Colorado; Fordham University, New York, New York; Georgetown University, Washington, District of Columbia; Spring Hill College, Mobile, Alabama; Loyola University, New Orleans, Louisiana; St. Louis Univer-

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sity, St. Louis, Missouri; University of Santa Clara, Santa Clara, California; Gonzaga University, Spokane, Washington; Holy Cross College, Worcester, Massachusetts. All but one of these stations originally owed their existence to the energetic initiative of Reverend Frederick L. Odenbach, *S. J.*, of the John Carroll University, Cleveland, Ohio, who during the years 1909 to 1911 persuaded the faculties of the various institutions of their opportunity to make substantial contributions to scientific knowledge in this field at comparatively small cost. They were at first united into a Jesuit Seismological Service with a central station in Cleveland. But this arrangement lasted only until 1912.

The details of the reorganization into the present Association partly as the result of the kindly interest of Dr. Arthur L. Day and Mr. Harry O. Wood, were published in a recent issue of the *Bulletin* of the Seismological Society of America (16: 3, 1926).

During the time from 1912 to 1925 Father Francis A. Tondorf, *S. J.*, of Georgetown University, did more than anyone else in the Jesuit group to keep alive public interest in seismology. By his lectures, writings, and especially by his regular and prompt reports of earthquakes, he stimulated the press, and through it scientific men and the people at large, to seek further information on seismological subjects. To keep pace with the growing interest, he steadily improved the equipment of the Georgetown station until he had in the Galitzin vertical component the most sensitive instrument in the country. In return for the data given them, the Associated Press furnished Father Tondorf copies of all reports on earthquakes that came over the wires. These reports were printed and distributed by Father Tondorf under the name of Press Dispatches and were much appreciated, especially by foreign seismologists. In addition to the monthly reports of earthquakes recorded by the Georgetown station, Father Tondorf also printed an Annual Report. He also found time to undertake such fundamental research as that carried through with Mr. Stuart B. Moore on the nature and causes of traffic vibrations in roadways. Father Tondorf is now planning to add to the equipment of Georgetown two horizontal-component Galitzin seismographs.

The second station in importance in the group which organized the Jesuit Seismological Association is that at Fordham University, New York. Until three years ago this station was equipped with only an eighty-kilogram Weichert seismograph. But that year a gift of ten thousand dollars for the purpose by Mr. William Spain of New York made possible the erection of a new station-building and the importation of two Milne-Shaw seismographs. One of these was installed in the

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autumn of 1924, the other late in 1925. Very recently, Mr. Spain has generously donated to the Fordham station three Galitzin seismographs. These are now under construction in Esthonia. Fordham will shortly take its place beside Georgetown among the best-equipped stations in the world. Besides publishing monthly reports of the earthquakes recorded at the station, Fordham communicates by cable with the international center at Oxford.

The station at Regis College, Denver, under the direction, since its beginning, of the Reverend A. W. Forstall, *S. J.*, has maintained an uninterrupted series of records. A number of minor improvements have been made at the station. The monthly reports are distributed to a much wider circle of observatories throughout the world than formerly.

The stations at Gonzaga University, Spokane, and at the University of Santa Clara have remained in continuous operation and now issue reports regularly. The small Weichert seismograph at Spokane normally registers unusually large amplitudes. Its records are of great importance for the earthquakes in Montana.

The stations at Spring Hill College, near Mobile, and at Loyola University, New Orleans, have furnished valuable data particularly for Caribbean and Central-American earthquakes. The station at Canisius College, Buffalo, has been in continuous operation though it has not been possible to resume publication of its reports. With the appointment last fall of Reverend George J. Brunner, *S. J.*, as director, the station at Loyola University, Chicago, which had been idle since 1912, was put back into continuous operation and has obtained some excellent records.

A new first-class station is being established by St. Xavier College, Cincinnati. It will be equipped with two long-period and two short-period Wood-Anderson horizontal-component seismometers, with a short-period Wood-Anderson vertical, and with a long-period Galitzin vertical-component seismograph. The first of the instruments has just arrived.

The St. Louis University station has kept the eighty-kilogram Weichert in continuous operation and has issued monthly reports for the years 1924, 1925, and 1926. During the years following the retirement of the first director, Reverend John B. Goesse, *S. J.*, the credit for maintaining the station in condition for operation is due entirely to the devoted Meteorologist of the University, Brother George E. Rueppel, *S. J.* At present the St. Louis University has under construction two new stations which will be described in some detail at the Cambridge meeting of the Eastern Section of the Seismological Society of America.

The Jesuit Seismological Association has established at Saint Louis a Central Station which serves as a clearing house for information for

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the benefit of the member-stations. It has arranged to cooperate very closely with Science Service and with the United States Coast and Geodetic Survey in the preliminary determination of the epicenters of all important earthquakes recorded in this country. Science Service defrays the cost of telegraphic reports to Washington and to Saint Louis, on which a double determination is made and then averaged. The determination thus becomes available to the press through Science Service very soon after each earthquake. The arrangement was made at the beginning of the year 1926 and has worked well. Great credit is due the officials of Science Service for this public-spirited undertaking. Altogether, the stations belonging to the Jesuit Seismological Association and also its Central Station have met with the heartiest cooperation, not only on the part of Science Service and the United States Coast and Geodetic Survey, but also on the part of other organizations, particularly the Canadian Government stations and individual stations in other parts of the world.

St. Louis University,
St. Louis, Mo.

C—SEISMOLOGICAL WORK OF THE U. S. COAST AND GEODETIC SURVEY[1]

N. H. Heck

The U. S. Coast and Geodetic Survey has been operating six seismological stations: San Juan, Porto Rico; Cheltenham, Maryland; Chicago, Illinois (at the University of Chicago, formerly operated by the U. S. Weather Bureau); Tucson, Arizona; Sitka, Alaska; and Honolulu, Territory of Hawaii (station formerly at magnetic observatory has been removed to the University of Hawaii where it is operated as a cooperative station). A Wood-Anderson torsion seismometer of the teleseismic type has been in operation at Tucson for a year and we are now able to appraise the results. There are Milne-Shaw seismographs at Chicago and Honolulu and recently the recording apparatuses have been rebuilt so that the time-recording is greatly improved. At the other observatories there are obsolete instruments, the Bosch-Omori, giving good records of severe earthquakes but missing practically all others. Replacements at Sitka and Porto Rico are part of the program as these are seismic regions of great importance without first-class instruments anywhere. Replace-

[1] Abstract of Report to Prague Meeting, International Geodetic and Geophysical Union.

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ment at Cheltenham is not contemplated at present, since it is but a short distance from the first-class station at Georgetown. Probably the operation of seismographs at Cheltenham, except continuation of the Bosch-Omori, will be for experimental purposes.

The collection of data on felt earthquakes is becoming more complete. The Weather Bureau has continued to make reports and this is the back-bone of the reporting system. In addition, state geological surveys, various universities, and other institutions are making reports, and at times of earthquakes great numbers of miscellaneous reports come in. Even with all this, there is scarcely enough, in many cases, for proper delineation of isoseismal lines.

The *Seismological Report* of the Coast and Geodetic Survey summarizes all earthquake activity felt within the United States and the regions under its jurisdiction, and earthquakes recorded in the same region. Since with sufficiently sensitive instruments the latter class would include earthquakes from all parts of the Earth, in general they are confined to those in the American continents, adjacent waters, and the Pacific region. Only in exceptional cases are others included since it is felt that existing stations cover well all the remaining parts of the Earth. Annual summaries give tables and maps showing the activity during the year. Preliminary epicenters are determined when practicable. The report includes analysis of records of stations of the Coast and Geodetic Survey and of cooperating institutions which do not publish reports.

Immediate determination of epicenter, chiefly for the region that has been outlined, is made in cooperation with Science Service and the Jesuit Seismological Association, and numerous seismological stations throughout the region. A first determination is made for press purposes within twenty-four hours and another, when all reports are in, is sent to all cooperating stations. The latter is useful in interpretation of phases at the various stations since gross errors are avoided in determining phases.

The report does not ignore the important geodetic operations in California in connection with the earthquake investigation there but this subject is adequately covered by Dr. Day, as chairman of the Advisory Committee in Seismology of the Carnegie Institution of Washington.

Tidal records of stations of the Coast and Geodetic Survey and cooperating organizations throughout the region outlined above are examined for evidences of seismic sea-waves.

Other government activities in seismology include the geological investigation of the more important earthquakes by the U. S. Geological

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Survey; the U. S. Bureau of Standards develops instruments; and the work of the Weather Bureau has already been noted. The U. S. Navy contributes reports of seismic waves experienced by its vessels and those of the merchant marine which send reports to it.

It has been found that much valuable information regarding various phases of earthquakes is in the Japanese language and is not likely to be translated by the Japanese. The Coast and Geodetic Survey has found that Government facilities for translation of Japanese do not extend beyond letters and short pamphlets. Accordingly, it has asked the American Geophysical Union to consider suggesting to the National Research Council the desirability of arranging for translation of highly important seismological information not now available. It is believed that a number of organizations are sufficiently interested to be willing to pay for such material.

U. S. Coast and Geodetic Survey,
Washington, D. C.

REPORT OF PROGRESS IN SEISMOLOGICAL WORK IN CANADA

THE SEISMOLOGICAL WORK OF THE DOMINION OBSERVATORY, OTTAWA

ERNEST A. HODGSON

Seismology is essentially a science requiring international research; furthermore, it has come to be rather minutely subdivided and specialized; finally, it may be observed that the data of the science are scattered and that a stock-taking of amounts and values of these is in order. We have in these circumstances the several reasons for presenting this paper, at this time, and before this, the Section of Seismology, of the American Geophysical Union.

The seismological work of the Dominion Observatory may be viewed in the light of (1) the records compiled, (2) the publications issued, (3) the present routine followed, and (4) the research-program in contemplation.

Considering this work in its relation to international effort it may be said that copies of any of the records at Ottawa are available to research workers of other countries on application. The publications are also available on request of those to whom they are likely to be of value. As regards the routine and research, these will be modified, whenever possisible, to fit in to greater advantage with the programmes of other countries.

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Speaking of seismological work as a phase of the modern specialization in science, it should be observed that the peculiar limitations and advantages of any station should be recognized and the work undertaken there be chosen so as to take full advantage of the situation obtaining. It does not pay to attempt work which requires too great a change in present equipment. This is the policy which has been followed at Ottawa, although increasing facilities are now making it possible to undertake more extensive research.

As a step toward eliminating the scattering and waste in seismological resources it was thought well to take advantage of the opportunity here presented of outlining those of the Observatory, in the way of records, publications, routine, and research, in order that other seismological organizations may know in what respects this institution may be able to cooperate with them in their work.

The records compiled date back to 1905, when the late Dr. Otto Klotz, afterwards Director of the Observatory, was given charge of the division of seismology, terrestrial magnetism, and gravity, of that institution. At that time a pair of Bosch, horizontal, photographic seismographs were purchased and installed; a Wiechert, eighty-kilogram, mechanical-registration, vertical seismograph was added in 1912. In 1915 a two-component Mainka, mechanical-registration, horizontal seismograph was set up at Dalhousie University, Halifax, and a similar instrument was placed, the same year, at the University of Saskatchewan, Saskatoon. In 1922, two Milne-Shaw seismographs began recording at Ottawa, in a specially-constructed vault, the floor of which is fifteen feet below ground and the roof six feet below ground-level. In 1925 a single component, Milne-Shaw seismograph was secured for a new station at the Experimental Farm at Ste. Anne de la Pocatiere, on the south shore of the St. Lawrence, near the centre of the seismic area.

The records from the Bosch seismograph have been carefully preserved whether earthquakes were registered or not. From April 1, 1908, to the present, this series is practically complete. The records are carefully preserved. Ten sheets are stored, without roll or fold, in each of the heavy manila filing envelopes provided. These are well indexed and are filed, on edge, in a special steel cabinet. The time-notations are especially good. Time, as recorded, is in general correct to within less than a second throughout. The constants of these seismographs were not determined very often during the earlier years and they can be known only approximately for most of the interval covered up to December 1, 1923. One component has been air-damped, the other magnetically damped throughout. The readings of the earthquakes and all memo-

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randa for the series up to November 30, 1923, are preserved in a set of ledgers. Since that time another system has been in use, which will be described later in connection with the Milne-Shaw records.

Until October 15, 1920, the records from the Wiechert vertical seismograph were preserved only in the case of large earthquakes. Up to that time, a great deal of difficulty had been experienced with the temperature-control of the seismograph. The control having been attained, the records have been preserved ever since, whether earthquakes were registered or not. The same remarks as to filing, time-markings, constants, and recording of memoranda apply to these seismographs as were outlined in the preceding paragraph.

The records from Halifax have been preserved at Ottawa, only in the case of large earthquakes. When stored at the Observatory they are filed flat in the manila envelopes designed for that purpose. The time-markings at Halifax have been checked for some years by a telegraph company's signal, recorded once an hour on the seismograph itself along with the minute signals from a fairly good contact-clock. The time cannot be depended on, however, nearer than within two or three seconds, even if the company's signals were correct. We have reason to believe these are also out at times. The constants of the seismographs are known within rough limits only. They were determined at the time the instrument was placed, and again in August, 1920. The data were recorded in the Ottawa record ledgers up to November 30, 1923. They are since taken care of by the system now in force.

Until July 1, 1925, the seismograms from Saskatoon were preserved at Ottawa, only in the case of large earthquakes. Since that date all have been forwarded to Ottawa and filed there along with the records of the Ottawa seismographs. The time as recorded has not been very good and no efficient check was provided except for the first year or so. Within the last few months, however, a radio set has been installed and steps are now being taken to insure an efficient time-service for the records at Saskatoon. The constants are not well known. They were determined when the instrument was set and again in September, 1922, when it was moved to the new Physics Building of the University. The notes with regard to this instrument were entered in the Ottawa record ledger until November 30, 1923, and subsequently in the system at present in use.

The records from the Ste. Anne instrument have all been preserved. They, too, are filed vertically along with the other records in the special envelopes. The constants are well determined and with sufficient frequency to insure the reliability of the determined figures. The time is checked at least once a day by radio and a signal recorded on the seismo-

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gram by the observer listening in. The records are developed at Ste. Anne, but forwarded to Ottawa to be read. The data are cared for in the card-system in use at the Observatory.

The Milne-Shaw seismographs are, at present, the chief instruments of the Ottawa station. No. 17 has been recording continuously since May, 1922. No. 23 was used as an experimental seismograph until November, 1923. (See Pub. of the Dom. Obs., Vol. 7, No. 1.) Since then both instruments have recorded continuously, No. 17 as an east-west component and No. 23 as a north-south component. The records are also filed flat in the heavy envelopes. The constants are determined frequently and are always known. The time-system is the same as that used for the other seismographs of the Observatory and may be depended on, as recorded, to within a fifth of a second. The data to November 30, 1923, were entered in the record ledgers. Since then the entries have been on cards.

In each of the paragraphs referring to records, mention has been made of the fact that in November, 1923, a new system of recording was adopted. It is not necessary to describe this in detail here. It was published in the *Bulletin* of the Seismological Society of America, Vol. 14, No. 4, December, 1924, pp. 265-273, and in *Travaux Scientifiques,* Serie "A," Fascicule 2, pp. 89-120, of the Section of Seismology of the International Geodetic and Geophysical Union. The method adopted December 1, 1923, has been maintained rigorously ever since with but minor changes. It may be stated here that the system has been defined in minutest detail in a set of typewritten instructions covering over 200 pages, the whole fully covered by index and cross references. This insures uniformity of procedure, and a record of that procedure for future reference. All changes when adopted are at once reduced to writing and form part of the supplementary pages of the organization instructions. It was intended that this outline should be published, but this has been abandoned because of the rather obvious reason that it can serve well only the station for which it was designed. It should be pointed out, however, that this reduction of routine to writing cost a great deal of time and effort but that it has already paid and will long continue to pay large dividends in efficiency of operation and the elimination of repetition. (It is proving very useful just now in the emergency created by a change in personnel in the case of the stenographer of this division.)

The change in the system most worthy of note is that in the method of filing the record cards. The change was effected, beginning January 1, 1926. A whole month is now represented by a series of cards (one to each quake as before) filed vertically on end in a single drawer of a specially constructed cabinet. Tabs insure that a 3/10-inch lap reveals

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the index-edge of each card, front and back. Any card or group of cards may be removed at will for the entering of data; the whole month's records may be carried to a desk by simply pulling out the drawer, which, standing upright, forms a holder for the cards, preserving the index-edges in plain view.

Besides the seismograms, the daily records of the anemograph, the microbarograph, and the thermograph are preserved for reference. The weather maps, supplied by the Meteorological Service, are also preserved on file. An interesting correlation of the records from the Milne-Shaw seismographs and from the thermograph with the daily weather maps, all laid out in order and photographed, one week at a time, for the year 1926, is awaiting careful study for the possibilities which may lie therein as regards the phenomena of microseisms.

Supplementing the records of the instruments and the data entries in the ledgers or on the cards now used, monthly seismological bulletins have been issued since April 1, 1908. A complete set of these covers the time from then until now. Every earthquake, of which a trace appeared on an Ottawa seismogram, received a serial number and was reported by bulletin entry. Up to April 20 of this year a total of 2783 quakes had been recorded and their seismograms read for the bulletin. These are, of course, all on file.

Bulletins are also received at Ottawa from other seismological stations. A special file preserves these for use in the location of epicenters. Some of the reports from other stations date back to 1903; the file is fairly complete after 1908; practically all that were received at Ottawa since 1914 are there available. These records are of value for reference. They are carefully indexed by stations and by years and are stored in heavy manila envelopes in a convenient file. They serve, moreover, to remind us of the very excellent work which has been done in past years and which compares favorably with the best of our programs of today.

A most important part of the records assembled at the Observatory is represented by its library. Over 15,000 volumes are to be found there, about a quarter of which may be considered as dealing with geophysics. These are being regularly augmented by fresh purchases of new books required in the various divisions. Practically all geophysical (and astronomical) publications of value (in English, French, and German), and certainly all that have been brought under review and found of value in the work there, are subscribed for regularly. Besides these paid subscriptions there is a very considerable exchange-list. Nearly all the observatories in the world exchange publications with the Dominion Observatory. As the volumes of paid or exchange periodicals are completed

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they are bound, catalogued, and added to the library. The series of many of the periodicals extend back for one or two decades. The librarian, Mr. Labbe, has at his hand a great store of valuable records. The current material is kept fully up-to-date. All are fully catalogued and are instantly available.

The publications of the Dominion Observatory, dealing with seismology, have been written by Dr. Otto Klotz, by Ernest A. Hodgson, or by W. W. Doxsee. They have appeared, either in the series known as the *Publications of the Dominion Observatory* or in outside journals.

We may first consider the Publications list. At first the seismological numbers were scattered through the various volumes, along with the publications on astronomy and on other branches of geophysics. From now on seismological numbers will be confined to certain volumes. At present Volume 7 is being reserved, to be completed with such numbers only. The list of those numbers of the Publications dealing with seismology, to date, is as follows:

(1) Stereographic Projection Tables, Otto Klotz, LL. D. Pub. Dom. Obs., Vol. 1, No. 1 (1913).
(2) Earthquake of April 28, 1913, Otto Klotz, LL. D. Pub. Dom Obs., Vol 1, No. 5 (1913).
(3) Earthquake of February 10, 1914, Otto Klotz, LL. D. Pub. Dom. Obs., Vol. 3, No. 1 (1915).
(4) Seismological Tables, Otto Klotz, LL. D. Pub. Dom. Obs., Vol. 3, No. 2 (1916).
(5) The Effect of Cooling on a Cement Pier, Ernest A. Hodgson, M. A. Pub. Dom. Obs., Vol. 5, No. 2 (1921).
(6) The Location of Epicenters, 1917-18, Ernest A. Hodgson, M. A. Pub. Dom. Obs., Vol. 5, No. 4 (1921).
(7) The Location of Epicenters, 1919, W. W. Doxsee, M. A. Pub. Dom. Obs., Vol. 5, No. 9 (1922).
(8) The Location of Epicenters, 1920, W. W. Doxsee, M. A. Pub. Dom. Obs., Vol. 8, No. 2 (1922).
(9) Report of the Seismologic Division for 1923, Ernest A. Hodgson, M. A. Pub. Dom. Obs., Vol. 7, No. 1 (1925).
(10) The Location of Epicenters, 1921, W. W. Doxsee, M. A. Pub. Dom. Obs., Vol. 7, No. 2 (1925).
(11) The Location of Epicenters, 1922, W. W. Doxsee, M. A. Pub. Dom. Obs., Vol. 7, No. 3 (1926).

In No. 9 of this list (the Report of the Seismologic Division for 1923), pp. 55-57, appears a complete list of all the papers of the three authors

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published in outside journals up to January 1, 1924. Dr. Klotz did not publish any papers later than the period covered by that list. Subsequent publications in outside journals by Messrs. Hodgson and Doxsee will be found listed in the *Bibliographical Bulletin* of the Eastern Section of the Seismological Society of America, in which bulletin all subsequent papers by these authors will be listed as published.

The *Bibliographical Bulletin* of the Eastern Section of the Seismological Society of America has just been mentioned. This is also, in part, a contribution to seismology by the Dominion Observatory. The publication is edited at that institution, which has also, so far, furnished the supplies and postage required. It is a branch of international seismological work which, it is felt, has an important part to play. Cooperation from authors in all parts of the world is being earnestly sought. The possibilities are great. It is hoped that the bulletin will receive the support of all interested in seismology or its applications, not only in the way of subscriptions, but also in the reporting of papers which should receive mention therein. Brief reviews of the papers reported add greatly to the value of such entries.

The seismological work of the Dominion Observatory is, at present, carried on under the general supervision of R. Meldrum Stewart, the Director, by the following staff: Seismologist, Ernest A. Hodgson; Assistant Seismologist, W. W. Doxsee; Stenographer, Miss A. I. Dearth. It may be dealt with as (1) routine, (2) research.

The present routine is defined very rigidly by the typed outline previously mentioned. For present purposes it may be classified as (*a*) seismic records, (*b*) locations of epicenters, or (*c*) publications to be completed. These will be considered in the order named.

As regards seismic records it may be said that the various seismographs (the Bosch, two components, photographic; the Wiechert vertical, mechanical registration; the Milne-Shaw, two components, photographic, and an obsolete earth-tide instrument known as the "Deformation Instrument" and run for experimental and check-purposes) are maintained in constant operation. Since December 1, 1923, all of these instruments have been carefully checked for constants at frequent intervals and the results published in the monthly bulletins. The time-service of the Observatory furnishes minute-to-minute signals, correct to within a fifth of a second. Seismological bulletins giving a report of the readings, made from the seismograms registered, are mailed to over two hundred outside seismological stations within the first few days of every month, covering the records for the month immediately prior. This

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part of the work has been directly under the care of Mr. Doxsee since September 1, 1925.

The second division of the routine is that of the preparation of a series of publications on the location of epicenters. The series was begun in 1911 by Dr. Klotz, carried from 1914 to 1919 by Mr. Hodgson, and has since been in care of Mr. Doxsee. The method of stereographic projection has been used throughout. Every earthquake of which a trace was recorded at Ottawa has been included in the investigations. From 1911 to 1922 an extended list of the data collected was published, even in cases where no epicenter was determined. Beginning with the Location of Epicenters for 1923—now in preparation—the practice will be to preserve all the data received but to include in the analysis only those which yield an unquestioned identification of at least one principal phase. This relieves the pressure of work due to the entering of a great number of data which are never to be used; but it does not appreciably reduce the value of the resulting publication.

Of the publications to be completed at the present time, that which is most in arrears is the series of reports of the seismological division for 1924, 1925, and 1926. Most of the material, to date, has been prepared, but opportunity for completing the work has been lacking. The issue for 1923 was the first of a new series of yearly publications on the work of the seismological division. It is hoped that this may be brought up to date in the near future. Another publication most pressing for completion is that of the St. Lawrence earthquake investigation. There are already some four hundred pages of notes carefully typed out on forms to facilitate analysis. The whole will run to at least five hundred pages of such notes. This material must be analyzed and reduced as far as possible to essentials for the publication proper. The notes must be in good form, however, for preservation and future reference. The work of investigation is practically complete with the exception of one item (the evidence furnished by the tide-records taken in 1926 as to any changes in level just below the mouth of Riviere Ouelle, subsequent to 1900). This work is now being completed by the Tidal Survey of Canada. Besides these publications which are to be completed, the *Bibliographical Bulletin* requires regular attention five times a year. It involves a considerable amount of reading and also much clerical work, which, however, have their compensations in the regular work of the division. It is essential that this publication appear regularly and promptly. A system has been developed whereby much of the work done incidentally from day to day may be automatically made a part of the

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set task of preparing this publication. Thus when it comes time to get out another issue much of the material is already in shape.

The research programme in contemplation at the present time involves the installation of two single-component Wood-Anderson seismographs in or near the seismic areas of Quebec. The instruments have been purchased and have been delivered to the Observatory where they are now being given a series of tests. The investigation in Quebec is a cooperative one, the general direction of which is being undertaken by the Dominion Observatory. During the summer of 1926 the Geodetic Survey of Canada undertook the work of placing a triangulation-net and a series of bench-marks in each of the two areas—one on the St. Maurice River, near Shawinigan Falls, the other on the Ste. Anne River near Seven Falls (the Ste. Anne River flows south into the St. Lawrence near Beaupre, P. Q., about twenty-five miles below the city of Quebec). That work was completed during the season of 1926.

The Topographical Survey of Canada had already begun a map of the St. Maurice area; they hope to issue this in the near future. They have undertaken also to make a special map of the area in the region of the Ste. Anne River. The aeroplane work was completed during the winter. The topography shown in these air-pictures of the snow-clad valley is truly remarkable. Anyone familiar with the cadastral plans of that part of Quebec knows of the long, narrow farms, each abutting on a river or a roadway. To look on one of the aeroplane-maps is to see a copy of the cadastral plan traced out faithfully by the fences and hedges with the added feature of visible relief.

The Geological Survey of Canada arranged a reconnaissance of each of the areas by Dr. J. W. Goldthwait, of Dartmouth College, Hanover, N. H. This was carried out during the summer of 1926. It is Dr. Goldthwait's opinion that neither of the vault sites chosen is near fault-lines which give evidence of having been active within recent geologic time. They are, however, close enough to faults which are active, that records may be obtained to advantage on the sensitive Wood-Anderson seismographs.

Commercial interests in the province have agreed to cooperate in this investigation. They have attended to the construction of the vaults. One of these is now ready for the seismograph and the other will be ready soon. They leave nothing to be desired as sites for seismographs. Time will be recorded by means of box chronometers manufactured by Nardin. These are now undergoing rating tests at the Observatory. They will be checked, when on location, by means of daily signals recorded on the seismogram by the observer listening in on the wireless signals.

The work of installing the instruments will begin as soon as they have

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been checked at Ottawa. This should be within the next few weeks. The records are being awaited with considerable interest.

As soon as the Wood-Anderson instruments are in place the Milne-Shaw will be removed from Ste. Anne de la Pocatiere. An attempt will be made to use it during the summer to test out the effect of wind and of traffic on some of the larger buildings which are used for triangulation-stations in the city surveys. This work is being undertaken at the request of the Geodetic Survey.

Incidentally it is hoped that further data will be secured as to the cooling effects in the case of a relatively high building which result when a hot afternoon is followed by a cool evening. A paper given by the author before this Section of Seismology at the meeting last year indicated the curious tilting oscillations which seem to be the result of such thermometric changes. The paper of last year referred to these oscillations in the case of a rock mass. Presumably the same phenomenon will be found in the case of buildings.

Having, then, outlined the records on hand, the papers published, the routine and the prospective research, nothing remains except to repeat that those responsible for the seismologic work of the Dominion Observatory are most anxious to place their resources, as far as possible, at the disposal of those in a position to make use of them, and are more than ready to receive from their co-workers in the science suggestions of such changes as may be considered advantageous to the work as a whole.

Dominion Observatory,
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SCIENTIFIC PAPERS

SEISMIC WAVES AND THE SURFACE-LAYERS OF THE EARTH

PERRY BYERLY

In California at present the lack of seismographic stations sufficiently closely spaced forbids the drawing of travel time-curves for local earthquakes and thus allows no direct conclusions to be drawn as to the structure of the surface-layers of the Earth. The most that can be done is to examine our local earthquake records from the one or two stations at which they are recorded, and to compare the actual wave-groups registered with those computed on the bases of structures of the surface-layers as concluded for Europe by seismologists there.

For certain California earthquakes, the travel time-tables of A. Mohoro-

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vičić, based on a discontinuity at depth fifty-seven kilometers, have offered a satisfactory solution, i. e., one which agreed with field evidence.[1] But certain nearby earthquake records offer a complexity of early arrivals which cannot be explained by these tables.

The recent work of Harold Jeffreys[2] offers another solution of European surface-structure, and it is worth while to see if such a structure will explain our complex records in California. It is noteworthy that Jeffrey's interpretation calls for simpler records for earthquakes at depths greater than about thirty-five or forty kilometers than for earthquakes of higher focus.

On April 27, 1924, a quarry at Corona, California, fired a large charge of dynamite. This caused an earthquake which registered at the Pasadena seismographic station. The exact time of occurrence of this earthquake was observed by Mr. Harry O. Wood and his associates, and a good record of it was obtained by Mr. Wood at his Pasadena station, a distance of 67.5 kilometers from the focus. Thus we have a California earthquake of which the focus and time of occurrence are known, but of which we have only one record. Mr. Wood and the writer have studied the record in some detail, and with Mr. Wood's permission it is discussed briefly here.

An interesting comparison to this seismogram is offered by the record obtained at Tacubaya of the earthquake which accompanied the eruption of Popocatapetl on October 16, 1920.[3] The distance to the station from the crater was 72.4 kilometers. The similarity of the two records is marked. On both records there are a number of marked new arrivals between the beginning of the record and the arrival of the maximum group. The tables of Mohorovičić account for no such groups.

The first arrival is very weak at Tacubaya and this group did not register on the Pasadena seismogram. The *iM* on the Pasadena record satisfies the S_g travel-time of Jeffreys, velocity 3.2 kilometers per second (where S_g represents the transverse wave which has travelled its whole path in the granite layer). The interval between the beginning of the Tacubaya record and its *iM* satisfies Jeffreys' (S_g—P_g) time.

The first arrival on the Pasadena record and the second on the Tacubaya record have the travel-times of Jeffreys' P which has been twice refracted at the base of the granitic layer (or perhaps reflected at this

[1] Bull. Seis. Soc. Amer., 16: (1) 1, March, 1926.

[2] London, Mon. Nat. R. Astro. Soc., Geophysical Supplement, 1: (8) 385, Dec., 1926.

[3] H. Camacho, Anales del Instituto Geologico de Mexico, 2: Nos. 1, 2, and 3, 1925.

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surface, since at this distance the travel-times for these two cases are nearly the same), if the granitic layer has a thickness of fifteen kilometers and Jeffreys' velocities in the two upper layers hold. No *S* which corresponds to this strictly is found, i. e., none which shows a travel-time nearly 1.7 times that of this group.

The next arrivals are larger than the previous groups, and therefore it is difficult to attribute them to a *P* which has been twice refracted at the base of the second layer, and their travel-times might be explained as such only if the thickness of this basaltic layer were fifteen kilometers, Jeffreys' velocities being assumed, whereas Jeffreys finds a thickness of twenty-five kilometers.

One of the large late arrivals might be explained as having travelled through the upper or sedimentary layer.

However, no definite conclusions can be drawn save that between the beginning of the records and the arrival of the maximum there are a number of marked new arrivals which are not called for by the tables based on a single discontinuity at a depth of fifty-seven kilometers. And the large amount of energy in some of these is difficult to explain on the assumption that they are *P*-waves travelling through Jeffreys' layers, even though they be his diffracted waves.[4] It is interesting to note that the apparent surface-velocities of some of these groups are the same as those of certain groups of surface-waves for distant earthquakes.

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SOME NEW WAVE-GROUPS OBSERVED ON THE RECORDS OF THE SOUTH PACIFIC EARTHQUAKE OF JUNE 26, 1924

JAMES B. MACELWANE, S. J.

(Abstract)

The study of the records of the earthquake of June 26, 1924, which occurred in the south Pacific Ocean, has revealed a large number of groups of waves which cannot be accounted for by the tables of travel-times now in use. Hence it was found necessary to calculate the time required to traverse other possible paths. This was done by the Wiechert-Herglotz method using much of the data published by Geiger and Gutenberg and applying Snell's law. The new groups are P_cS, P_cSS_cP,

[4] Cambridge, Proc. Phil. Soc., 23: (4) 472-481, Oct. 1926.

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PPPS, PPSS, PSSS, PPPS', PPSS', and *PSSS'*. These waves are served on many records. A few examples are here given.

Station	Δ°	New phases observed
Sydney	23.3	P_cP
Apia	49.8	P_cP, P_cS, S_cS
Batavia	63.4	P_cP, S_cS
Honolulu	87.3	P_cP, S_cS, P_cSS_cP (late), *PPPS, SPS*
Hyderabad	98.2	P_cSS_cP, *PPPS, PPSS, PPSS'*
Victoria	124.8	*PPPS, SPS, PPSS*
Cartuja	152.9	*PPPS, SPS, PPSS, PSSS*
Vienna	154.2	*PPSS, PPSS'*
Munich	156.8	*SPS, PSSS*
Zurich	157.9	*PSSS, PPSS, PPSS'*
Strasbourg	159.1	*PPPS, SPS, PPSS, PSSS, PPSS'*
Feldberg	159.6	*SPS, PPSS*
Paris	162.0	*SPS, PPSS, PPSS'*
Uccle	162.1	*SPS, PPSS, PPSS'*

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SIMPLE APPARATUS FOR SEISMIC MEASUREMENTS

PAUL KIRKPATRICK

The failure of the falling columns of Mallet, West, Milne, Omori, and Galitzin to attain to the dignity of precise seismometrical instruments appears to have been due to the fact that the true relation connecting the constants of the columns with the constants of the earth-motion necessary and sufficient for their overthrow was not known to these workers. This ignorance is not surprising since the columns used were subject to resonant disturbance by earth-vibrations of certain frequencies, and hence the mechanical problem involved was very complicated. The present paper describes a type of column, or as we shall say, a bar, which is braced at one side and suitably fitted with a bearing so that it is free to fall in one direction only. This arrangement has been found to eliminate all resonant vibration of the column and greatly to simplify the theoretical statement of the conditions governing its downfall.

By making the assumptions that the motion of the quake when the bar falls is simple harmonic, and that the bar in its erect position is not far from vertical it has been possible to obtain a complete solution of the problem of the motion of the bar. This solution is presented in a supplement attached to this paper so that the development may be con-

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sulted in its entirety if desired, but the only portion of which we have need at present is the conclusion that a bar will just be thrown down by a horizontal oscillation lying in its plane of rotation if the maximum acceleration of the motion has the value

$$a = g\theta\sqrt{1 + \frac{4\pi^2 R^2}{gLT^2}}$$

In this equation R is the radius of gyration of the bar, L is the distance from its center of mass to its axis of rotation, and T is the period of the oscillation. The angle through which the erect bar must be rotated before coming to the position of unstable equilibrium is ϕ.

This equation is substantiated not only by a rigorous derivation but also by an exhaustive experimental test. An oscillating table capable of horizontal simple harmonic motion of adjustable period and amplitude was employed. Every variable quantity represented in the above equation was varied widely, and of over five hundred observations every one conformed to the equation within the leeway of two or three per cent which the uncertainties of observation permitted.

If we consider a family of bars of similar construction and with parallel axes of rotation but differing in their angles of inclination it is evident that a quake of moderate intensity will overturn those bars which are inclined at the smaller angles, leaving the remainder standing. The critical value of ϕ which divides the fallen from the standing bars can therefore be determined with a precision depending only upon the number of bars used. But the equation shows that a knowledge of this critical angle will not, in general, suffice to determine the maximum acceleration, since this acceleration is also a function of the period of oscillation. The influence of the period can be suppressed only by making the whole second term under the radical sign a small quantity. Experiment shows that this may be done by a suitable choice of the form and dimensions of the bar, so successfully, at least, that for all oscillations with periods greater than one-fourth of a second the maximum acceleration is fully determined by the critical angle, with an error which can not be greater than six per cent and which is much less in nearly all cases. It is probably not worth while at present to strive for greater accuracy at this point, since the errors resulting from the assumption that the earth-motion is simple harmonic have not been investigated.

Further information may be derived from the bars. Referring again to the equation, one sees that a knowledge of the critical angle, as ob-

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tained by observing a given set of bars, gives an equation in which maximum acceleration and period alone are unknown. From a second set of bars, different from the first in their dimensions, another critical angle is observed, giving another relation between acceleration and period. The two equations are independent and together suffice to determine both the acceleration and the period. From these quantities the approximate amplitude is readily computed. These determinations are subject to three errors only. The first is the error in determining the critical angles; it may be made as small as desired by the use of a larger number of bars. The second is the error involved in the assumption that θ is small; this is entirely negligible for quakes of small intensity and rises only to about one per cent with very disastrous quakes. The third error is that of the assumption that near the time of maximum acceleration the earth-motion is simple harmonic. Assumptions of this kind have often been made, but never, so far as the writer knows, critically investigated. It is impossible at the present time to make a numerical statement of the exactitude of this assumption, but its validity becomes of less and less importance as the radius of gyration of the bars is diminished. A personal view is that errors of this sort can be kept below five per cent in the acceleration-determinations.

The bars which are now being used are of an inverted T-shape (see Figure 1). Nearly all of the mass is in the crosspiece, which is of lead. Near the ends of the crosspiece steel cups, taken from watch bearings, are located, and these cups rest over vertical steel needles fixed in a horizontal base-board. The upright member of the inverted T leans against an adjustable stop, which controls the magnitude of θ. The upright is two or three inches in length and the horizontal member about four. The center of mass of the system is perhaps two millimeters above the points of the supporting needles, giving the small radius of gyration required by theory. The bars are readily reset by tilting the entire base-board. No attempt has been made to determine the utmost sensitivity which is possible with such a bar but it has been shown repeatedly that shocks well below the threshold of perceptibility are dependably registered.

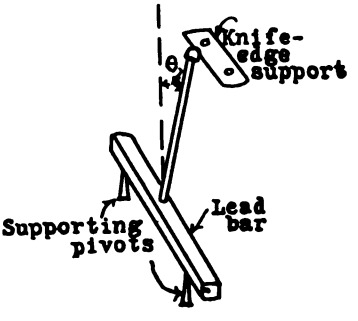

FIG. 1

Schematic diagram of simple apparatus for seismic measurements.

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MATHEMATICAL SUPPLEMENT

Consider a rigid bar of mass m, and of any shape, such as the rod of Figure 2. An axis of rotation is provided at x, horizontal, and perpendicular to the plane of the diagram. The distance from x to the center of mass of the bar will be designated by L, and the angle between the direction of L and the vertical by θ. Inclination to the right indicates a positive θ.

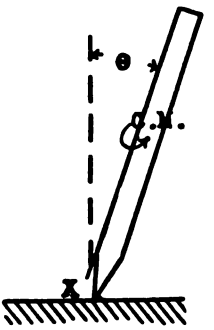

FIG. 2

Diagram for development of mathematical theory.

Let the axis undergo a horizontal acceleration, a, toward the right. This will produce a counter-clockwise inertial torque. Considering also the clockwise gravitational torque we have as the resultant (positive when counter-clockwise) torque

$$Q = m a L \cos \theta - m g L \sin \theta \qquad (1)$$

Restricting θ to small values this may be written

$$Q = m a L - m g L \theta \qquad (2)$$

Seismic accelerations are oscillatory in character, and more or less similar to the accelerations of simple harmonic motion. We shall investigate the behavior of the bar when subjected to horizontal simple harmonic motion in the plane of the diagram, of period T, and amplitude r. The acceleration of such motion is

$$\frac{4\pi^2 r}{T^2} \sin\left(\alpha + \frac{2\pi t}{T}\right)$$

Equation (2) then becomes

$$Q = \frac{4\pi^2 m L r}{T^2} \sin\left(\alpha + \frac{2\pi t}{T}\right) - m g L \theta \qquad (3)$$

Equating this torque to the rate of change of angular momentum we obtain the differential equation of motion of the bar

$$\frac{d^2\theta}{dt^2} - \frac{m g L \theta}{I} = \frac{-4\pi^2 m L r}{I T^2} \sin\left(\alpha + \frac{2\pi t}{T}\right) \qquad (4)$$

Introducing the constants A, B, and K, this becomes

$$\frac{d^2\theta}{dt^2} - A\theta + B \sin(\alpha + K t) = 0$$

The general solution of Equation (4) is found to be

$$\theta = C_1 e^{-\sqrt{A}t} + C_2 e^{\sqrt{A}t} + \frac{B}{K^2 + A} \sin(\alpha + K t) \qquad (5)$$

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The case which is of interest in this investigation is that in which the bar is initially at rest at some particular angle, θ', at the instant when $t = 0$. These conditions make possible the determination of the constants in equation (5). They are

$$C_1 = \frac{B}{2(K^2+A)}\left(\frac{K}{\sqrt{A}}\cos\alpha - \sin\alpha\right) + \frac{\theta'}{2}$$

$$C_2 = \frac{-B}{2(K^2+A)}\left(\frac{K}{\sqrt{A}}\cos\alpha + \sin\alpha\right) + \frac{\theta'}{2}$$

Inserting these values we obtain

$$\left.\begin{aligned}\theta = &\left[\frac{B}{2(K^2+A)}\left(\frac{K}{\sqrt{A}}\cos\alpha - \sin\alpha\right) + \frac{\theta'}{2}\right]e^{-\sqrt{A}t} \\ &+\left[\frac{-B}{2(K^2+A)}\left(\frac{K}{\sqrt{A}}\cos\alpha + \sin\alpha\right) + \frac{\theta'}{2}\right]e^{-\sqrt{A}t} \\ &+\frac{B}{K^2+A}\sin(\alpha + Kt)\end{aligned}\right\} \quad (6)$$

It will be found convenient to expand equation (6) and recombine it into the following form

$$\left.\begin{aligned}\frac{K^2+A}{B}\theta = &\left(\frac{K^2+A}{B}\theta' - \sin\alpha\right)\cosh\sqrt{A}t \\ &-\frac{K}{\sqrt{A}}\cos\alpha\sinh\sqrt{A}t + \sin(\alpha + Kt)\end{aligned}\right\} \quad (7)$$

The conditions described above are physically realized by allowing the upper end of the bar to rest against a stop, the position of which may be varied if it is desired to change θ'. If this system be subjected to horizontal simple harmonic motion as described above, the bar will not rotate or rise from its stop unless Q attains positive values at some time in the cycle, that is, unless the acceleration at some time exceeds $g \tan\theta'$, or for small angles simple $g\,\theta'$. If the maximum acceleration slightly exceeds this threshold value, the bar will rise from its supporting stop but will drop back as the acceleration decreases again, without reaching its vertical position. If the acceleration be still further increased, however, the bar will eventually be carried over the vertical position and will fall down on the other side. The critical acceleration sufficient to do this is a function of θ', of T and r, and of the constants of the bar. We proceed to find its value.

The downfall of the bar means that θ passes permanently to negative values. Since the sine term in equation (7) merely oscillates about zero

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it is required that the sum of the first two terms of the right member shall remain negative for all large values of t. The hyperbolic functions approach equality, so that after t has become large these first two terms may be replaced by

$$\left[\frac{K^2+A}{B}\theta' - \sin\alpha - \frac{K}{\sqrt{A}}\cos\alpha\right]\sinh\sqrt{A}t$$

Since the hyperbolic sine is always positive its coefficient must become negative if the bar is to upset, the threshold of instability being defined by the condition

$$\frac{K^2+A}{B}\theta' - \sin\alpha - \frac{K}{\sqrt{A}}\cos\alpha = 0 \tag{8}$$

It has been stated that the bar first begins to rise when the acceleration attains the value $g\,\theta'$. This is stated thus:

$$\frac{4\pi^2 r}{T^2}\sin\left(\alpha + \frac{2\pi t}{T}\right) = g\,\theta'$$

But at this instant $t = 0$, so we have a as defining equation for sin α

$$\frac{4\pi^2 r}{T^2}\sin\alpha = g\,\theta'$$

or

$$\left.\begin{aligned} \sin\alpha &= \frac{g\,T^2\theta'}{4\pi^2 r} \\ \text{and} \\ \cos\alpha &= \sqrt{1-\sin^2\alpha} = \sqrt{1-\frac{g^2\,T^4\,\theta'^2}{16\,\pi^4 r^2}} \end{aligned}\right\} \tag{9}$$

Inserting these values in (8), replacing the values of A, B, and K, and simplifying

$$\theta' = \frac{4\pi^2 r}{g}\sqrt{\frac{m\,l}{m\,l\,T^4 + 4\pi^2 I\,T^2/g}} \tag{10}$$

or

$$\frac{4\pi^2 r}{T^2} = \theta'\sqrt{g^2 + \frac{4\pi^2 I\,g}{m\,L\,T^2}} \tag{11}$$

Therefore maximum acceleration, where R is the radius of gyration, is

$$\theta'\sqrt{g^2 + \frac{4\pi^2 I\,g}{m\,L\,T^2}} = g\,\theta\sqrt{1 + \frac{4\pi^2 R^2}{g\,L\,T^2}}$$

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SECTION OF METEOROLOGY

SYMPOSIUM ON NEEDS AND POSSIBILITIES OF MEASUREMENTS OF ULTRA-VIOLET LIGHT IN SOLAR SPECTRUM AND OF THE OZONE-CONTENT OF THE HIGH ATMOSPHERE

DESIRABILITY OF SUCH MEASUREMENTS

C. F. Marvin

In opening this discussion upon the subject of ultra-violet radiation, it is unnecessary for me to elaborate upon the desirability of securing quantitative observations of such radiation and of pursuing investigations thereof. During the past fifty years great progress has been made in collecting exact observations of the total radiation received from the Sun, and the time is now at hand when we need to know more about the *quality and composition* of this radiation. How much of it is infra-red, how much visible and luminous, and how much ultra-violet, and so forth. What are the effects of rays of particular classes on human affairs? How do they vary from season to season, year to year, and place to place? These are questions of importance, not alone to the meteorologist but to the biologist, the botanist, and the plant physiologist; to the medical profession; to those interested in hygiene, sanitation, and public health; and to the industries as well.

The Weather Bureau is drawn into the question, both by its own personal interest and also as a public agency to which all those interested apply for observational data and statistics. As a matter of fact, sufficiently simple and dependable instruments are not yet available by which reliable and comparable observations can be secured. The methods and apparatus for making such observations are still in the laboratory stage of evolution.

One purpose of this symposium is to bring out a full discussion of what we may call the present laboratory state of the science in order that the instrument-makers and designers may go to work intelligently to produce instruments which can be safely put into the hands of the average observers with a reasonable assurance of accurate, comparable observations.

One of several proposals that have been made is that certain standard dyes contained in quartz tubes and exposed to sunshine for definite times will serve to show ultra-violet intensities by the amount of fading of the dye. The question of purity, permanence, and comparability comes in

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here to such a high degree as to make simple methods of this kind too uncertain to be acceptable.

Great interest will be awakened by the valuable papers of this symposium and the important contributions they will make to the theoretical side of the question. The practical problem back of all is a standard type of instrument capable of analyzing solar radiation into certain major parts which can be measured in appropriate standard units of some kind and by means of which uniform observations can be secured from many widely distributed stations.

U. S. Weather Bureau,
Washington, D. C.

OZONE IN THE UPPER AIR

W. J. Humphreys

It appears to be well established, and now generally accepted, that there is an appreciable amount of ozone in the upper air and practically none at all in the lower. The whole of this ozone, seemingly variable in quantity, would make a layer only three to four millimeters thick at standard temperature and pressure. That is, it amounts to only one part, roughly, by weight, in two million of the whole atmosphere. With the exception of xenon it is the rarest of all aerial gases, yet one of the most important. Its importance is owing to its power of absorption of radiation and to its selectivity in respect to the wave-lengths absorbed.

It is well known that diatomic oxygen rather strongly absorbs radiation of wave-length round about 1800 Ångström units, and that some of this oxygen is thereby transformed into the triatomic variety, or ozone. Now, ozone has a broad band of metallic-like absorption centered at about wave-length 2500, and extending more and more feebly several hundred units on either side. In consequence of this absorption the ozone is reverted to ordinary or diatomic oxygen. Presumably, therefore, the relative amounts of ordinary oxygen and ozones sixty and seventy kilometers above the surface are, to some extent, at least, determined by the relative intensities of these two portions of the solar spectrum, the ozonizing and the deozonizing. At the base of the stratosphere, however, or, rather, at the top of the troposphere, the ozone presumably quickly reverts to ordinary oxygen owing to the presence there of an appreciable amount of water vapor. Apparently, then, we may assume, as a crude first approximation, that oxygen is being converted into ozone and ozone converted to oxygen at some definite level, say sixty kilometers above the surface of the Earth; that all the ozone that reaches the top of the troposphere is there quickly reverted to oxygen, and that

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ozone is neither formed nor destroyed, as such, to any appreciable extent, at any other levels. To the extent that this assumption is true there must be a continuous circulation of oxygen and ozone between these two levels, oxygen up and ozone down, with the excess of production over destruction of ozone at the upper level equal to its destruction at the lower. Furthermore, since the total amount of the ozone present at any time between its upper and lower levels is very small in comparison with the other gases present, say one part in 500,000, it follows that the oxygen-ozone circulation must be very slow, even approaching ordinary diffusion, and the density distribution of the ozone roughly that which it would be if determined by gravity alone.

From these considerations one would infer that when the base of the stratosphere is highest, that is, when the center of an anticyclone is passing, there will be the least amount of ozone overhead; and the most when the stratosphere is lowest, or when a cyclone is passing. Besides, as a lifting of this base by only three kilometers, or, say, from nine to twelve kilometers above the surface, reduces the pressure at that base by fully one-third, and as the lifting of this base from cyclone to anticyclone occasionally is even more than here assumed, it follows that we may expect the ozone to be much greater over cyclones than over anticyclones. And that is just what observations show. We should also expect that the amount of ozone would be less in the upper air during summer and autumn, when the base of the stratosphere averages high, than during winter and spring, when, on the average, it is lower. This, too, is supported by observations. Finally, we should expect the ozone over middle and higher latitudes to be at least twice as great as it is near the equator, owing to the corresponding five or six kilometers difference in the level of the base of the stratosphere. This inference has not yet been checked by observations.

The above assumption that the ozone is distributed in the stratosphere substantially as determined by gravity, and therefore mainly in the lower portion of this region, is not in accord with certain observations that indicate its level to be forty-five to fifty kilometers above the Earth. However, these observations involve such uncertainties as might well call for a suspension of judgment. Besides, if the ozone is mainly at these high levels it is not obvious how the quantity of it could be affected by the height of the barometer or time of the year, relations that appear to be easier to determine, and perhaps therefore more reliable, than the height at which the ozone chiefly occurs. At any rate, the assumption of a gravity distribution of the ozone in the lower fifty kilometers, or thereabouts, of the stratosphere, is still allowable, it is believed, and especially so since it suggests definite test-observations—measurements at various

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latitudes, and in conjunction with air-soundings that give the height of the base of the stratosphere.

It is practically certain that the ultra-violet limit of the solar spectrum as observed at the surface of the Earth is fixed by the ozone of the stratosphere. If there were no ozone in the atmosphere, the flood of ultra-violet radiation, at least down to 2,000 Ångström units, that would get through to the surface of the Earth would be destructive to many organisms, as now constituted. On the other hand, if the great ultra-violet absorption-band of ozone were shifted a little, say 500 Ångströms, towards the visible, seeing, so long as there were eyes to see, would nowise be affected, but it might well be that under these conditions, the total absence of all anti-ricketic radiation, the human race, and many others, would soon disappear.

In still another, but less important way, the ozone of the upper air affects the surface of the Earth. It has powerful absorption-bands in the far ultra-red, where Earth-radiation is strong. It therefore keeps the surface of the Earth at a slightly higher temperature than it otherwise would have.

Clearly, therefore, the ozone of the atmosphere, though small in amount, is very important, and its accurate measurement at various latitudes and under different conditions a matter of considerable scientific interest. Such measurements, already begun in a few places, are made with a suitable spectroscope, and a hopeful approach to accuracy and standardization appears to have been attained.

It is reasonably certain, of course, that the amount of ozone in the upper air reflects in some measure the quantity, and quality, of solar radiation, but it is so very sensitive to barometric changes (really, we believe, to the height of the base of the stratosphere) that it will be very difficult to separate with certainty the purely solar effects, at least those of brief duration, from those due to other causes. However, this is no excuse for minimizing efforts, but rather a good reason for making the measurements of the ozone in the upper atmosphere as highly accurate as possible, and as abundant as practicable, consistent with this indispensable precision.

LITERATURE

There is a considerable literature on the absorption of radiation by ozone, and its amount and distribution in the atmosphere. The following few papers, however, with the references they in turn cite, cover the subject fairly well:

LADENBURG AND LEHMANN. Ann. der Phys., 21:305 (1906).

CHARLES FABRY. Proc. Lond. Phys. Soc., 39:1 (1926).

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DOBSON, HARRISON, AND LAWRENCE. Proc. Roy. Soc., 114: 521 (1927).

CABANNES AND DUFAY. J. Physique, 8:125 (1927).

U. S. Weather Bureau,
Washington, D. C.

ULTRA-VIOLET SOLAR RADIATION

EDISON PETTIT

The work of Abbot and his colleagues [1] has shown that the radiation from the Sun varies and that the variation is most pronounced in the violet end of the spectrum. Whether we regard the variation as due to a change in temperature, a variable transmission of the outer solar envelope or a variable emissivity, this effect on the ultra-violet is to be expected. Dobson [2] in England using a photographic method, measured the ultra-violet solar radiation transmitted by silver-films on thirty-four days in 1922, and found variations as great as five hundred per cent, and a standard daily range of thirty per cent outside the atmosphere. It occurred to the writer that the uncertainties of photography could be eliminated by measuring the radiation directly with a thermo-couple; that disturbances of the atmosphere could be made differential by standardizing the ultra-violet with the green region of the spectrum which varies only slightly; that the accuracy could be increased by making the apparatus automatic, which would permit an increase in the number of observations, and that the combination of this procedure with the favorable atmospheric conditions on Mount Wilson might lead to results of some interest.

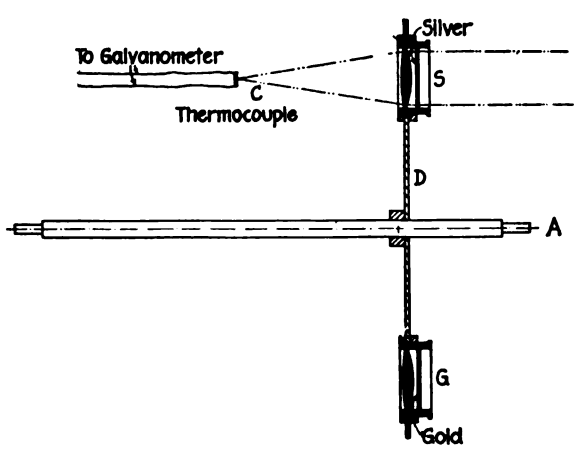

FIG. 1

Diagram of optical system of the ultra-violet solar radiometer.

This was accomplished by an apparatus constructed as follows: In Fig-

[1] Ann. Astroph. Obs., Smithsonian Inst., 4: 206 (1922).

[2] Proc. R. Soc., London, 104: 252 (1923).

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ure 1, *A* is a spindle carrying a disk, *D*, having two cells set diametrically opposite one another. Cell *S* contains a quartz lens and plate, both

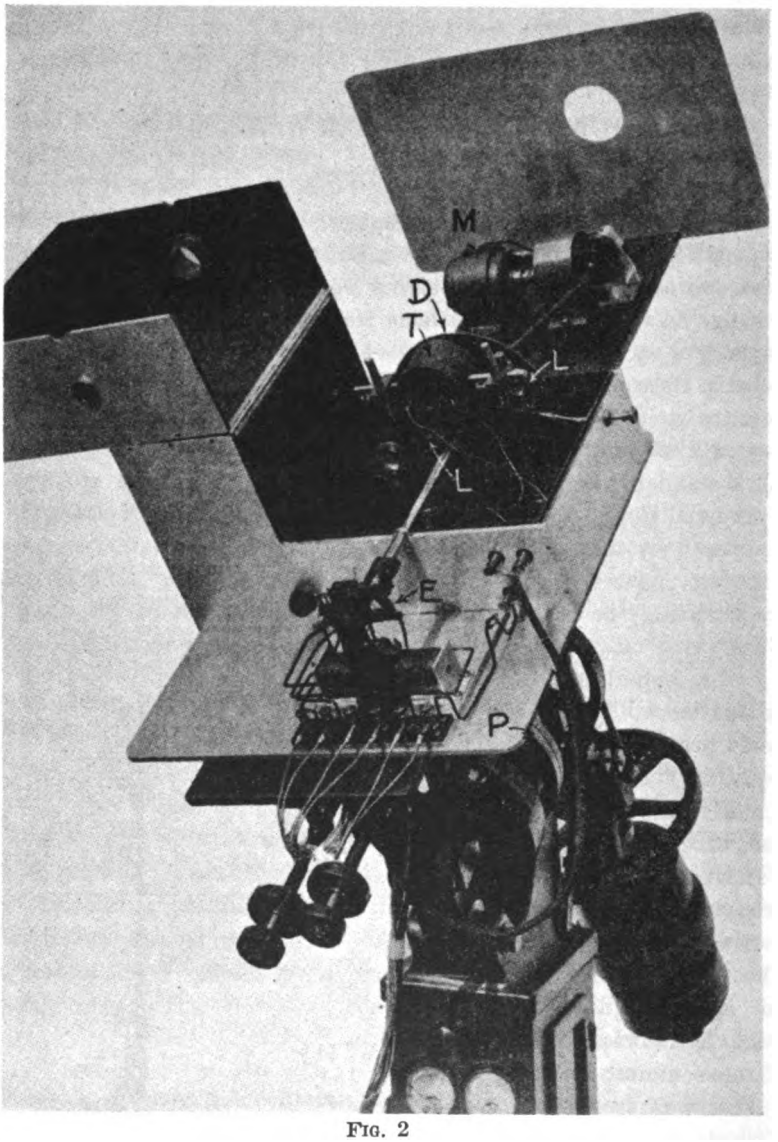

FIG. 2

Ultra-violet solar radiometer at Tucson.

silvered chemically on their inner surfaces with two coats of silver. Cell *G* contains a similar quartz lens and plate, both coated on the inner surfaces with gold by sputtering. These are crossed lenses, giving mini-

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mum spherical aberration, and are of one-inch aperture and two inches focal length. The separators are formed to fit the surfaces producing practically air-tight contacts. Diaphragms in contact with the plates are used to adjust the galvanometer-deflections in the apparatus on Mount Wilson, but not in the Tucson apparatus, about to be described. Exposed to the Sun, the lens forms an image of it, one-half millimeter in diameter, in ultra-violet light of wave-length 0.32 μ, on one junction of the compensated thermo-couple *C*. An escapement attached to the spindle *A*, operated electrically by a contact-clock, causes the image to fall first on one, then on the other junction of the compensated thermo-couple, then permits the disk to rotate a half revolution, and repeats the process substituting the gilded lens which transmits green radiation in wave-length 0.50 μ. The deflections thus produced in the galvanometer attached to the thermocouple by the ultra-violet and green radiations from the Sun are recorded photographically on a moving plate and determine the ratio ultra-violet to green radiation every four minutes.

Figure 2 shows a radiometer recently installed at the Desert Sanitarium of Southern Arizona at Tucson. In this instrument the thermo-couple is in an air-cell having a large heat-capacity, and not in a vacuum as on Mount Wilson. This makes it possible to compare the galvanometer-deflections themselves, since the sensitivity is constant, there being no secular change due to state of vacuum. The motor *M*, working through a friction-disk exerts a continuous torque on the spindle which is permitted to rotate only at intervals of one minute when the escapement *E* is released by the magnets. An air-cell thermo-couple *T* having quartz windows and receivers one mm square is connected to a D'Arsonval galvanometer in the room below. *D* is the disk carrying the lenses *L*. A wire running over a pulley *P* on the polar axis has the moving plate attached to the other end upon which are registered photographically the deflections of the galvanometer.

Figure 3, upper part, shows reproductions of the galvanometer records for October 19 and 20, 1926. The inside rows of dots are produced in each case by the radiation transmitted by silver, $\lambda = 0.32\ \mu$; the outside rows are due to the radiation transmitted by gold, $\lambda = 0.50\ \mu$. The heavy lines are hour-angle marks, put on by the contact-clock, and indicate local solar time. It will be seen that the ultra-violet light is zero for some time after sunrise, reaching a maximum at noon, whereas the green radiation has a sensible value at sunrise and rapidly approaches its maximum. The lower part of Figure 3 shows a graphical solution for each of the plates. The logarithm of the ratio, ultra-violet to green radiation, is plotted against secant *Z* obtained from the hour-angle.

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This plot is a straight line from which two values are taken, that for the zenith, secant $Z = 1$, and that for no atmosphere.

Figure 4 shows march of the monthly means of the ratio, ultra-violet to green, since May, 1924, compared with Dobson's and Harrison's measurements of ozone (below), Abbot's measurements of the solar constant,

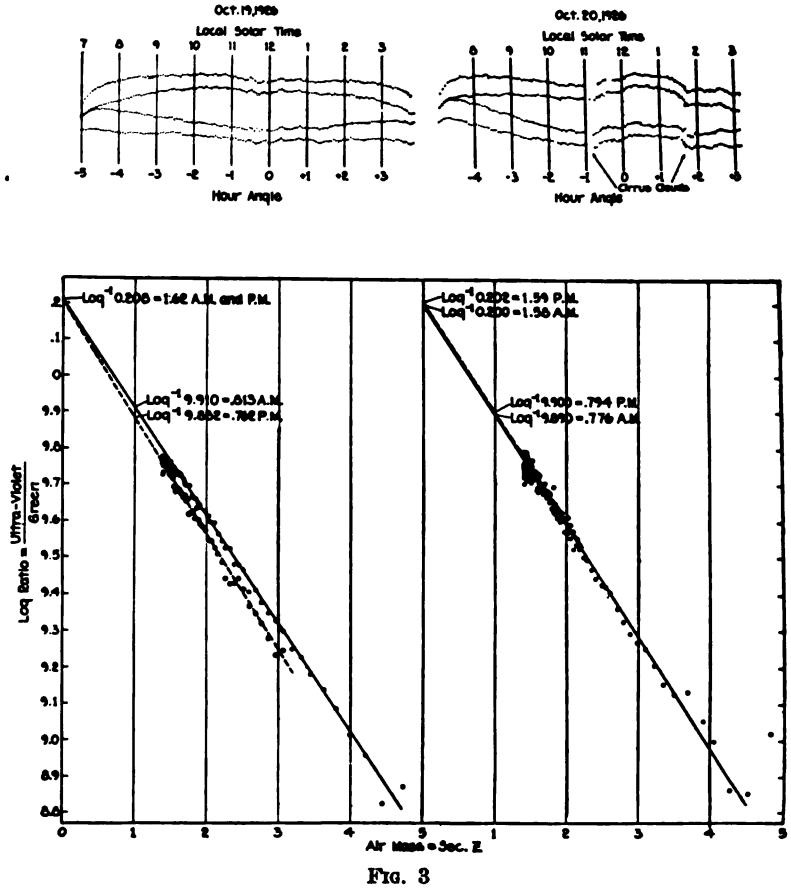

FIG. 3

Radiometer records and plots for October 19 and 20, 1926.
(At left with a typical day with afternoon run affected by haze and at right a day with no haze in the afternoon.)

and the Mount Wilson daily sunspot group-numbers (above). Considerable correspondence will be noted in the general trend of the last three curves. The ultra-violet values are for no atmosphere, but practically the same curve would result if the values for one atmosphere were used, so nearly are the atmospheric disturbances eliminated.

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The ozone-curve seems to run counter to the ultra-violet curve. The ozone-curve represents a seasonal variation, although it is difficult to see how the obvious explanation of changing solar declination can apply,

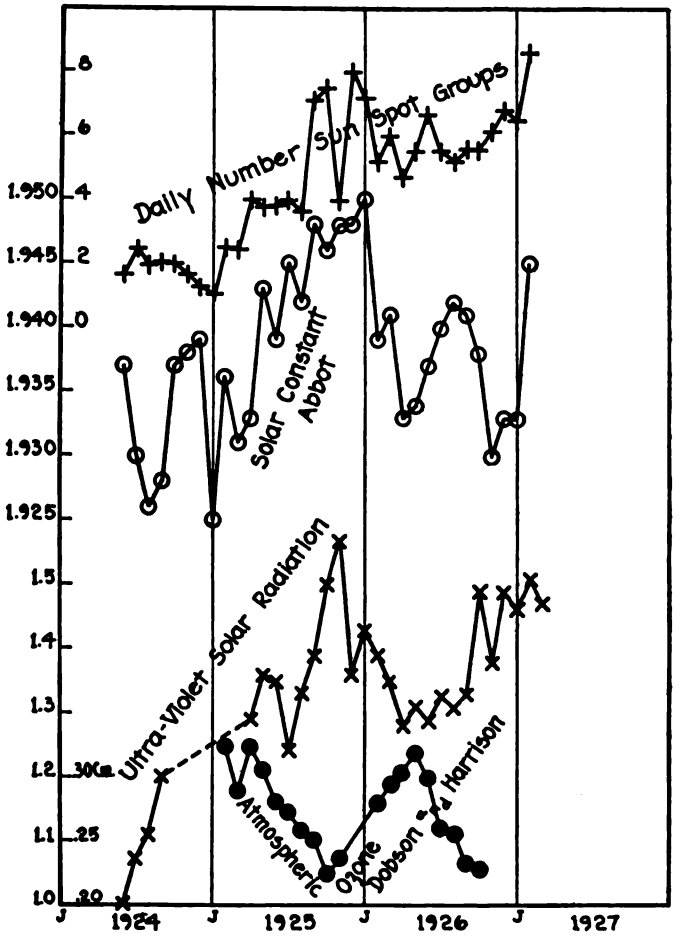

FIG. 4

March of the monthly means of atmospheric ozone, ultra-violet solar radiation, solar-constant, and sunspot group-numbers.

since the time of maximum ozone lags behind the time of maximum insolation, rather than the contrary, which we might expect. Probably it is too early to draw conclusions in this connection.

That variations in the ozone-content of the atmosphere do not sensibly affect these measurements of ultra-violet radiation was shown by plac-

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ing a tube of ozone in the optical path of the instrument and varying the pressure in the tube. In this way it was shown that an increase of one hundred per cent in ozone decreases the ultra-violet measurements only five per cent, while complete elimination of ozone increases them only three per cent. That the transmissions of the filters are not affected by exposure to sunlight was shown by increasing the area of the diaphragms placed in front of the lenses, thus exposing previously unexposed portions of the filters after the apparatus had been in operation

TABLE 1

Station	H(cm)	E/E_0 Obs.	$E/E_0 = e^{-kH}$ Comp.		Air mass $= B/B_0$	Log E/E_0 Obs.
			Rayleigh	Cabannes Dufay		
Mt. Whitney (Smithsonian)...	350000	0.615	0.592	0.569	0.653	9.7889
Mt. Wilson.....	174200	0.480	0.519	0.489	0.812	9.6812
Tucson.....	76000	0.370	0.479	0.452	0.916	9.5682
Pasadena.....	25800	0.325	0.466	0.440	0.969	9.5199
Oxford (Dobson)..	6400	0.315	0.452	0.427	0.993	9.4983
Sea-level.....	0	.....	0.448	0.422	1.000	.....

$$k = \frac{32\pi^3(u-1)^2}{3N\lambda^4} \quad \text{(Rayleigh)} = \frac{8\pi^3(u^2-1)^2}{3N\lambda^4}\left(\frac{6+3\rho}{6-7\rho}\right)$$

(Cabannes and Dufay)

more than two years. The deflections increased in proportion to the increased area. In January of the present year the cells were taken apart and examined. No trace of tarnish or other defect was observed in the films. A careful determination of the transmission of both plates was made, and this will be repeated toward the end of the year to check further the stability of the metallic films.

Table 1 shows a comparison between the observed and computed atmospheric transmissions for several elevations for ultra-violet light of wave-length 0.32 μ. A very considerable disparity is noted as sea-level is approached. This is shown graphically in Figure 5. Here the straight lines are the theoretical vertical transmissions computed from Rayleigh's

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law of scattering and the modified formula of Cabannes and Dufay[8] which takes polarization into account. It will be noted that for air-masses less than 0.8 (which is equivalent to an altitude of 6,000 feet) the transmission is greater than that called for by the theory, and at lower altitudes it is much less, being only 0.70 as great near sea-level.

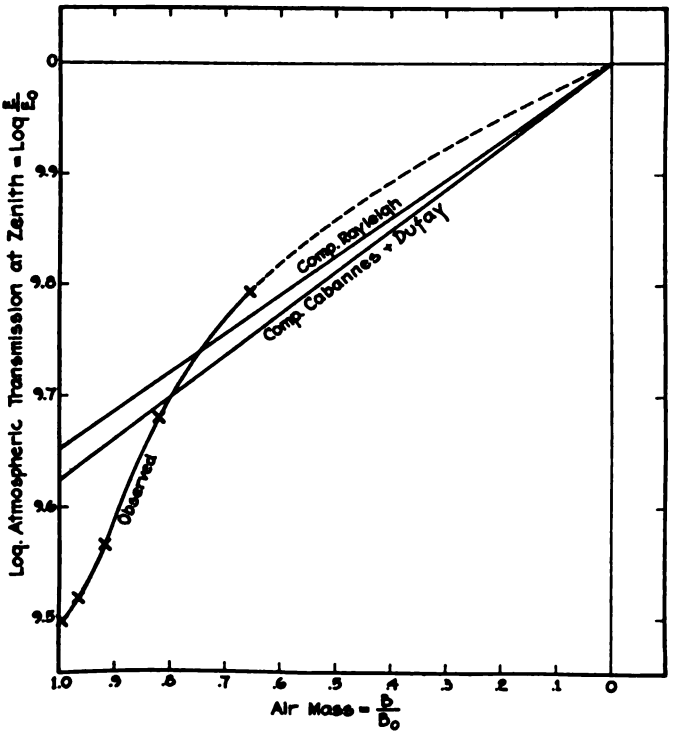

FIG. 5

Comparison of the observed and computed atmospheric transmissions for ultra-violet light for $\lambda = 0.32\,\mu$.

A direct comparison between Pasadena and Mount Wilson gave sixty-five per cent on a fairly clear day, which is in fair agreement with the value sixty-eight per cent obtained from the transmission in Table 1.

Measurements of sky-radiation effective on a horizontal surface determined photographically in wave-length 0.32 μ show, for air mass 1.3, one-twentieth that of direct sunlight on Mount Wilson, and one-fourth that of direct sunlight in Pasadena on a fairly clear day. Under these conditions the radiation in this wave-length, falling on a horizontal

[8] J. physique et le radium, 7: 257 (1926).

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plane surface from the Sun and sky combined in Pasadena is 0.8 that on Mount Wilson, the greater radiation from the sky making up for the deficiency from direct sunlight to some extent.

A peculiar meteorological phenomenon has been noticed both in the Mount Wilson and Tucson measurements. When the sky is perfectly clear so that no whiteness can be seen up to the limb of the Sun from sunrise to sunset the morning and afternoon observations agree in giving nearly the same results, i. e., the intensity of the ultra-violet light is the same for a given hour-angle east and west of the meridian. Ordinary clouds and haze do not seem to affect the ratio ultra-violet to green remarkably, but haze of another kind does. Estimates of the radius of the corona about the Sun due to sky whiteness are made at intervals during each day's run and are recorded on a scale of zero to ten. Generally, this whiteness is nearly zero until 11 A. M., then it begins to rise rapidly, attaining a value of six or seven by 1 P. M., after which it gradually increases to eight or nine by sunset. This haze has the appearance of smoke and in the afternoon may be seen from Mount Wilson, filling the valley below and rising in clouds considerably above the mountain. Figure 3 illustrates, at the right a nearly perfect day, and at the left a typical day affected by haze in the afternoon. On account of this effect, only morning observations have been used to study the solar variation. It is possible that this phenomenon is connected with atmospheric ionization, and the afternoon runs may furnish material for its study.

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ANNUAL VARIATION OF THE SUN'S SPECTRUM IN THE REGION 3200 to 2900 ÅNGSTRÖM UNITS

GEORGE WINCHESTER

The intensity or variation of the spectrum in the violet and ultra-violet region is ordinarily measured by means of a thermo-couple or bolometer-arrangement. The physical, chemical, and physiological properties of the ultra-violet end of the spectrum are evidently not closely related to heat, and obviously any measurement based on the phenomenon of heat is unsatisfactory. The physiological properties of the region 3400 to 2900 *Å* have recently attracted considerable attention and some dependable method of measurement other than one based on the phenomenon of heat would be very acceptable. At the present time the threshold values of certain metals seems to point in a promising direction. Einstein's photo-electric equation between the energy absorbed

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and that retained by an electron freed from a metal by ultra-violet light is

$$\tfrac{1}{2}\, mv^2 = hv - w \quad \text{where } w = hv_0$$

v_0 being the low frequency limit for that particular metal.

Now suppose several metals with long-wave limits between 3400 and 2900 Å units are mounted in photo-electric cells; each cell will give us an indication of the intensity of a definite part of this region. The cells may be calibrated against each other; for example, by means of an ultra-violet monochromator. And thus by the method of subtraction the intensity of certain rather narrow bands in this direction may be measured photo-electrically.

If the variation in intensity is being determined a certain check might be obtained by means of Schumann plates read by means of a micro-photometer.

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PHOTOGRAPHIC SPECTROPHOTOMETRY IN THE ULTRA-VIOLET REGION*

LOYD A. JONES

It is assumed that the audience to which this paper is presented is interested chiefly in the application of photographic spectrophotometry to the measurement of energy distribution in solar radiation. The author feels some hesitancy in presenting a paper on this subject since he has not had any actual experience in solar-radiation measurements. A large amount of work has been done in our laboratory, however, on the application of photographic methods to the determination of the ultra-violet absorption characteristics of dyes and other selectively absorbing media and to the measurement of the spectral distribution of sensitivity in photographic material.[1] Although the application of such methods to the measurement of solar radiation undoubtedly presents certain problems not involved in the work in which we have had most experience, yet many of the fundamental principles are common to both types of work. It is hoped that a discussion of some of the methods which we have found useful and of the manner in which photographic materials should be used in order to eliminate some of the errors frequently encountered

* Communication No. 314 from the Research Laboratory of the Eastman Kodak Company.

[1] L. A. JONES AND O. SANDVIK. J. O. S. A. 12: (4) 401, April, 1926.

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may be useful to those who are interested particularly in the measurement of solar radiation.

The photographic plate has been used for many years in spectrophotometric work and owing to its sensitivity to radiation of frequencies outside the visible spectrum has become practically indispensable where it is necessary to work in regions of low or complete invisibility. Unfortunately, many methods of using the photographic plate for this type of work have been devised without a complete knowledge or due consideration of the inherent characteristics of these materials, with the consequences that results obtained have been more or less disappointing from the standpoint of repeatability and precision. Failures to obtain the required precision, which are usually traceable to improper usage or lack of knowledge of the fundamental characteristics of photographic materials, should not be considered as sufficient evidence for unqualified condemnation. The author feels very strongly that with proper experimental technique and intelligent interpretation of results the photographic method is capable of giving spectrophotometric data in the ultra-violet region equal or superior in precision to that obtained by any radiometric method. These remarks should not be interpreted to convey the impression that no satisfactory methods have been developed, for such is not the case. Some very good instruments have been devised and results of satisfactory quality have been obtained by their use. The literature of photographic spectrophotometry is voluminous and no attempt will be made in this paper to review the work that has been done in this field or to present a complete bibliography of the subject.

Before proceeding with a discussion of the instruments and method it may be advisable to state briefly some of the peculiarities of photographic materials which may give rise to errors when these materials are used for the measurement of radiation-intensities.

Intermittency effect. The photographic plate does not in general integrate correctly an intermittent exposure. An exposure (exposure, E = intensity, I, times time, t) of definite magnitude given as a series of intermittent flashes generally yields, upon development a lesser density than the same exposure applied continuously. Hence only under certain conditions will correct values of intensity be obtained if the exposing mechanism is of the intermittent type. This intermittency effect has been studied by Abney,[2] Schwarzschild,[3] Sheppard and Mees,[4] and many others. The most recent work is that by Davis[5] in which he

[2] W. de W. Abney. Phot. J. 18: 56 (1893).

[3] K. Schwarzschild. Astroph. J. 11: 92 (1900).

[4] Sheppard and Mees. Investigations on the Theory of the Photographic Process, p. 222, 1907.

[5] Raymond Davis. Bur. Standards Sci. Paper no. 528, 1926.

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shows that the difference between the density produced by equal continuous and intermittent exposure may be either positive or negative depending on whether the intensity factor of exposure, I, is greater or less than the optimal intensity, I_o, of the photographic material in question. For precision work in photographic photometry it is therefore undesirable to use intermittent exposing methods.

Failure of the reciprocity law. The density produced by a given exposure, E, is dependent not only upon the value of the exposure, $E = I \cdot t$, but upon the magnitudes of intensity, I, and exposure time, t. The relation between the values of intensity and time-factors in exposure and the magnitude of the resultant density has been studied by many workers in this field and the literature of the subject is very extensive. Perhaps the best known of this work is that of Schwartzschild [6] who formulated the law generally known by his name,

$$E = I \cdot t^p$$

where p is a constant. Kron [7] in 1913 carried out a very extensive research in this subject and from his results obtained the following equation

$$E = t \cdot I \cdot 10^{-\sigma \sqrt{\log \frac{I}{I_0} + 1}}$$

This subject has been given a great deal of attention in this laboratory during the past ten years and several papers reporting our results have been published.[8] It has been conclusively proven that the Schwartzschild equation is not correct and that the exponent p is not a constant. Our results which are based on many thousands of observations do not fit well the equation proposed by Kron as given above. An alternative equation which was suggested by Kron, but which he found did not fit his results satisfactorily has been found by us to fit the observed values more precisely than any other analytical expression thus far tested. The curve obtained by plotting the data in the form of "constant density curves" is of the catenary type and is expressed by the equation

$$E = \frac{I_o t_o}{2}\left[\left(\frac{I}{I_o}\right)^{\sigma} + \left(\frac{I}{I_o}\right)^{-\sigma}\right]$$

[6] K. Schwarzschild. Phot. Corr. p. 171, 1899; Astro. Phys. 11: 89 (1900); Beitr. z. Phot. Photen. d. Gestirne.

[7] Kron. Eder's Jahrbuch, p. 6, 1914.

[8] Loyd A. Jones and Emery Huse. J. O. S. A., 7: 12, 1079, Dec. 1923; 11: (4) 319, Oct. 1925; Loyd A. Jones, Emery Huse, and Vincent C. Hall. J. O. S. A., 12: (4) 321, Apr. 1926; Loyd A. Jones and Vincent C. Hall. J. O. S. A., 13: (4) 443, Oct. 1926; L. A. Jones, V. C. Hall, and R. M. Briggs. J. O. S A., 14: (3) 223, March, 1927.

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in which I_o (optimal intensity) and a are constants for any photographic material.

Relation between gamma and wave-length. If density, D, which is defined by the equation

$$D = \log_{10} \frac{1}{T}$$

where T is the transmission-coefficient of the silver deposit in question, is plotted as a function of log exposure a curve such as is shown at A in Figure 1 is obtained. A part of this curve is represented to within the

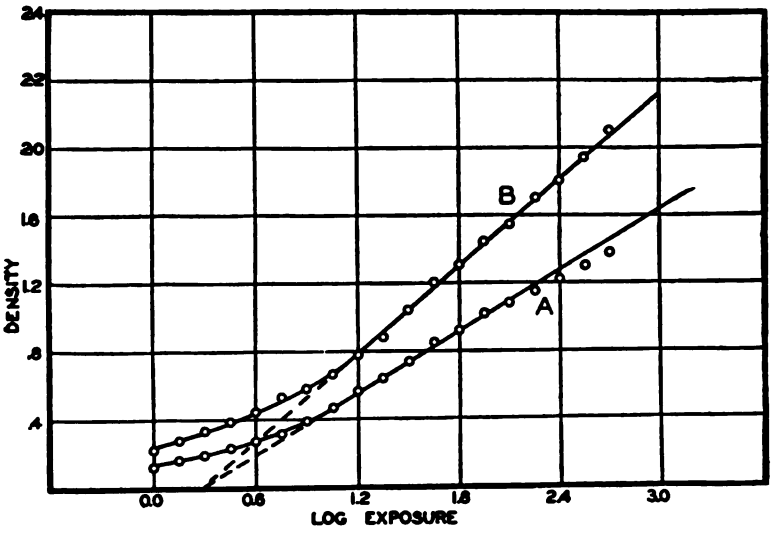

FIG. 1

Density-log E characteristic of a photographic plate.

limits of experimental error by a straight line. The slope (λ) of this line with respect to the x-axis is defined by tan a where a is the angle which the straight line makes the x-axis. The curve B in the same figure is the D-log E characteristic obtained with the same material but using a longer development time than was used in case of curve A. It is evident therefore that the slope of the straight line, $dD/d\log E$, is dependent upon the extent to which development is carried.

Moreover, for a fixed time of development, γ is a function of the wave-length of the radiation used in making the exposure. This dependence of slope on wave-length is shown graphically in Figure 2 which shows gamma plotted as a function of wave-length for various development-times, these curves applying to Eastman D. C. ortho plates. It will be

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noted that when the development time is short, low contrast, γ is fairly constant in value in the region from 3,000 to 4,000 Ångströms but when development is increased the γ obtained at 3,000 is very much less than that at 4,000. This relation between γ and wave-length of the exposing

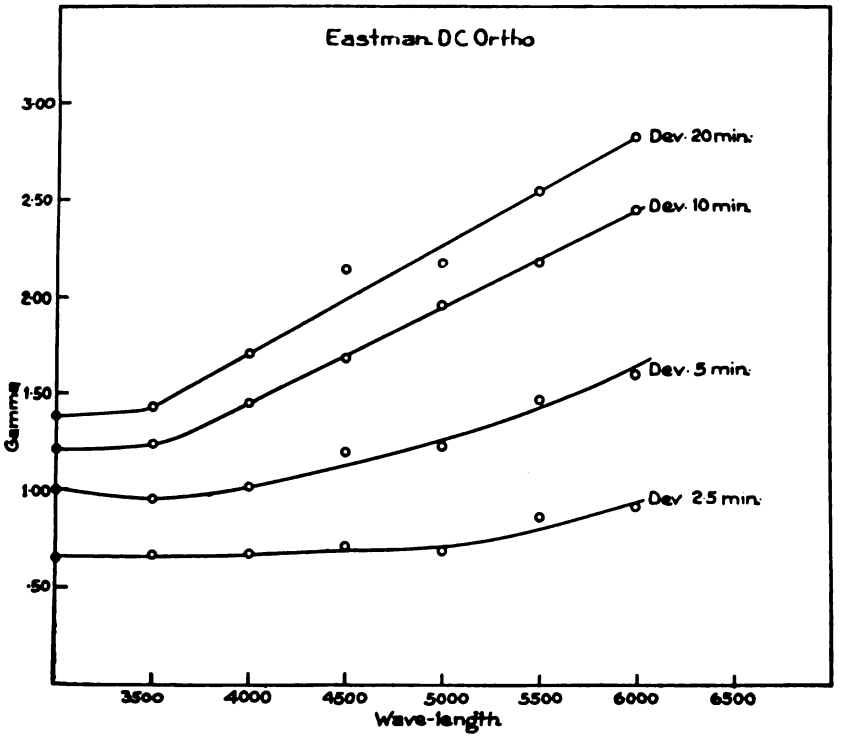

FIG. 2

Relation between wave-length and gamma for different times of development.

radiation is different for different photographic materials and in photographic spectrophotometry this relationship must be determined unless some method is adopted which automatically eliminates its effect. In a paper dealing with the sensitometric characteristics of photographic materials in the ultra-violet, Harrison[9] has published curves showing the relation between γ and wave-length for several different brands of photographic plates. His results indicate that for some plates γ is practically independent of wave-length in the region between 2,500 and 3,500 Ångströms, while for other materials there is an enormous variation within the same wave-length range. The author feels that it would

[9] HARRISON. J. O. S. A., 11: 341 (1925).

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be unwise to assume constancy of γ with wave-length even for materials of the same kind as used by Harrison without making a careful check on the particular emulsion-number being used. It is well known that different batches of emulsion may show slight variations in characteristics. While these variations of quality are not important for the practical purposes they may easily be sufficiently large to cause undue error in photographic spectrophotometry.

Non-uniformity of effective sensitivity. The most carefully made photographic materials may show measurable differences in sensitivity at various points, even when the area used is relatively small. These variations in sensitivity may be due to such factors as inequality in the thickness of coating, variation in the specific sensitivity of the emulsion, or slight differences in the rate at which development takes place at different points on the plate. While these inequalities in general are too small to be of consequence in the practical work to which these materials are usually applied they may become of great importance and of sufficient magnitude to introduce serious errors when an attempt is made to use these materials for the purposes of quantitative measurements.

Errors in development. It is very difficult to develop two samples of photographic material to exactly the same extent. This is due to many factors such as the variation in the rate of circulation of the developing solution over the surface of the plates or films, variation in temperature and time of development, etc. Of all the methods thus far devised for obtaining uniform development over a relatively large area it is probable that the so-called *brush* method proposed and described by Bloch [10] and Clark [11] is the best. Measurements made in this laboratory show that the errors attributable to lack of uniformity of development occurring when plates are developed in a tank or in a tray, are appreciably diminished by the use of the brush method.

Criteria of intensity equality. From a consideration of these characteristics the conditions under which two radiation-intensities are equal may be rigidly specified. Let two immediately adjacent small areas, A and B, on the surface of a photographic material be exposed to the two intensities to be compared. Let this exposed material be developed in such a way that the two areas received precisely the same treatment in developing, fixing, washing, drying, etc., and the resultant density be

[10] O. Bloch. Phot. J. 61: 425 (1921).

[11] W. Clark. Phot. J., 65: 76 (1925).

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measured under identical conditions of illumination and observation. Let the various factors involved be designated for convenience as follows:

Area	A	B
Intensity of incident radiation.....	I_1	I_2
Wave-length of incident radiation.....	λ_1	λ_2
Exposure time.....	t_1	t_2
Density.....	D_1	D_2

In general I_1 is equal to I_2 only when both exposures were made non-intermittently and when

$$t_1 = t_2,$$
$$\lambda_1 = \lambda_2, \text{ and}$$
$$D_1 = D_2$$

In case the two radiations being compared are not monochromatic the condition that $\gamma_1 = \gamma_2$ must be replaced by the requirement that the two heterogeneous radiations shall be of identical spectral composition.

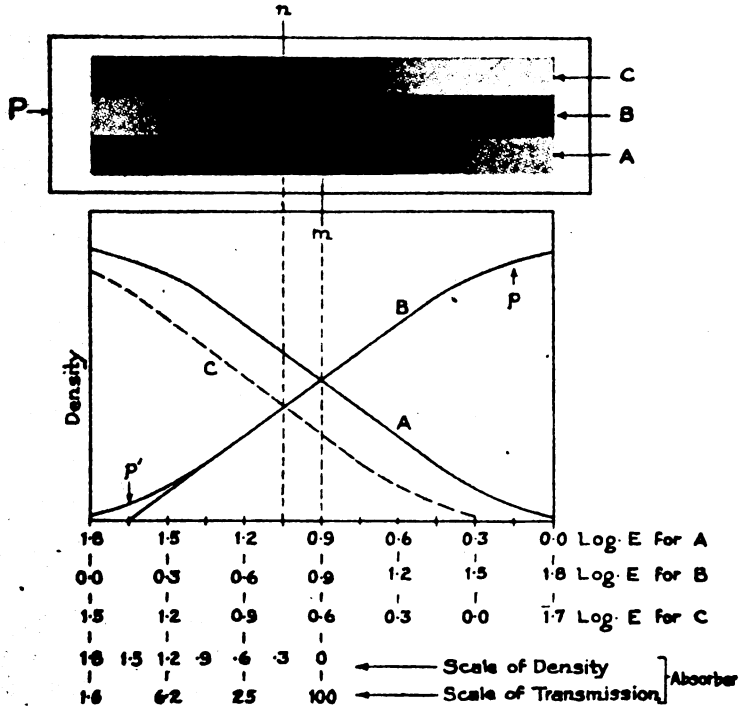

FIG. 3

Diagram illustrating method of measuring radiation-intensity.

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Any photographic spectrophotometric method to be entirely free from criticism must meet the requirements stated above. The validity of results obtained by a method not conforming to these conditions must be subject to doubt until it has been definitely proved that the error introduced by failure to meet the theoretical requirements in any particular case is within the limits of tolerances as established by the precision required.

A method for making spectral absorption-measurements in the visual region [12] has been developed in this laboratory which meets all of the requirements stated above. It is thought that this method can be extended with advantage to the measurement of solar radiation in the ultra-violet. The principle involved can best be explained by reference to Figure 3. The narrow rectangular area A represents the density produced by subjecting the photographic material to an exposure of which the time-factor, t, is constant and the intensity-factor, I, increases logarithmically from log $E = 0$ at the right-hand end to log $E = 1.8$ at the left-hand end. The relation between density and log exposure in this area is represented by curve A. The narrow strip B represents an exposure on the same material to the same light-source increasing from log $E = 0$ at the left-hand end to log $E = 1.8$ at the right-hand end. This density-distribution corresponds to curve B. It is evident that the two curves will intersect at a point midway between the zero points of the two strips, this intersection corresponding to the point at which the density on one is equal to the density on the other. Now if a third strip, C, is exposed under exactly the same conditions as A with the exception that a light filter of unknown absorbing power is placed between the light source and photographic plate the density illustrated by a strip C will be obtained corresponding to curve C. The point at which density-balance between strips C and B occurs is given by the intersection of the curve C with B and the lateral displacement of this with respect to the intersection point of curve A and B will be a direct measure of the absorbing-power of the unknown filter. In extending this to the measurement of intensity of radiation it is only necessary to make the exposure of strip C to a source of unknown intensity but of the same wave-length or spectral composition as that used in exposing strip B. The displacement of the point n, at which density-balance occurs, from the position of the point m is a direct measure of the intensity of the unknown source relative to that used in obtaining strip B. Emphasis is laid on the fact that the criterion of intensity-equality is that immedi-

[12] Loyd A. Jones. J. O. S. A., 10: 561 (1925).

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ately adjacent positions of the same photographic material give equal densities for equal exposure-times.

Obviously the development must be very nearly the same for the two areas and moreover from a consideration of the geometry of the figure the position of the point of balance is independent of the extent to which development is carried. Moreover it is not necessary that the density

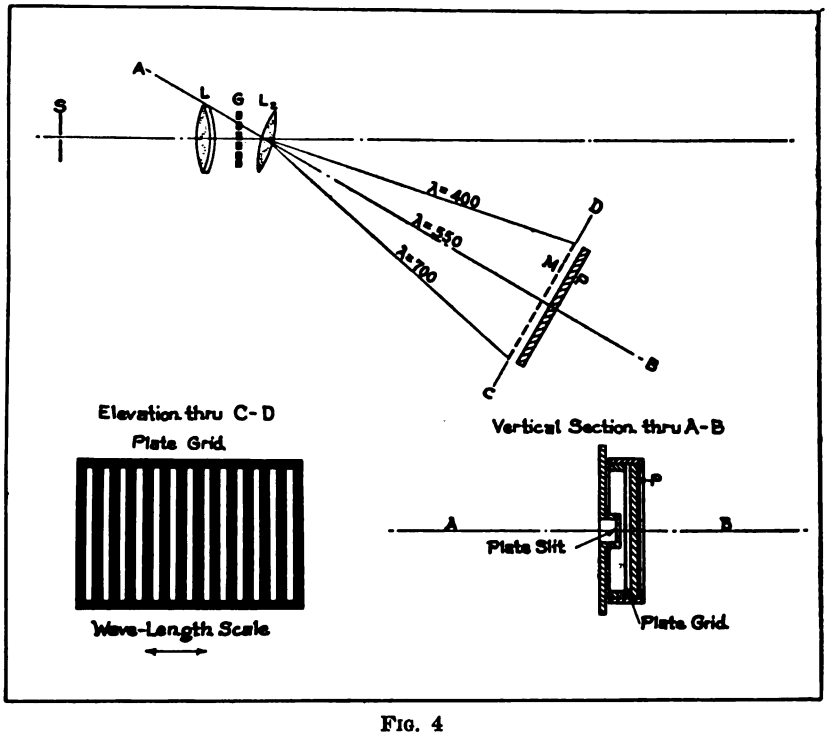

FIG. 4

Schematic drawing showing photographic spectrophotometer.

shall lie on the straight-line portion of the characteristic curve. It is obvious that the curves C and B must be of identical shape, assuming $\lambda_1 = \lambda_2$, hence the lateral displacement of curve C remains directly proportional to the relative intensity of the two sources regardless of whether or not the curves intersect on their straight-line portions.

The method of applying this to work in the visual region is illustrated in Figure 4 in the upper part of which is shown a schematic horizontal section through the instrument. The slit S is illuminated by suitable light-source. The light is collimated by lens L, dispersed by the diffraction-grating G, and focused on the spectrum plane CD by the lens L_2, the

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photographic plate being placed in the spectrum plane. A parallel line grid-plate, lower left-hand corner of Figure 4, is placed in contact with the sensitive surface in the spectrum plane, the grid-strips lying vertically. The photographic plate and grid are mounted in a holder which can be moved up and down, perpendicular to the plane of the drawing behind a plate-slit which extends horizontally through the spectrum, that is in the plane of the drawing. Between the lenses L and L_2 is mounted an adjustable sector-diaphragm by means of which the intensity of radiation incident on the photographic plate can be controlled.

The exposures are made as follows. The photographic plate with the shielding grid is moved vertically at a *constant linear velocity* while at

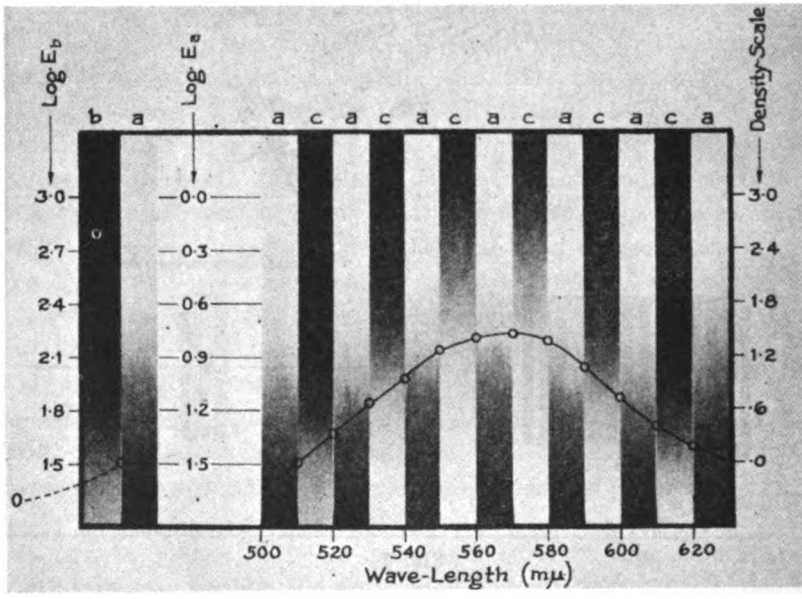

FIG. 5

Record obtained with the photographic spectrophotometer.

the same time the sector-diaphragm is closed in such a manner as to cause the intensity on the photographic plate to *decrease logarithmically.* In this way an exposure corresponding to the strip B in Figure 3 is obtained. The grid-plate is now moved laterally by a distance equal to the opaque strip, thus protecting from further exposure the areas which have been exposed and uncovering those areas which have not been exposed. Now the absorbing material to be examined is inserted, the plate moved vertically in the opposite direction at a constant uniform velocity, and the diaphragm opened in such a manner as to give an exposure *increasing* logarithmically thus giving an exposure through the filter as

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shown in strip *C*. For work in the visual a diffraction-grating is used giving normal dispersion. Hence a constant grid-spacing corresponds to constant wave-length difference. The grid-strip used is of a width corresponding to a wave-length band of five μ width. The appearance of the resulting plate after development is shown in Figure 5. A curve connecting the points of equal density gives directly the wave-length density-curve of the absorber. In Figure 6 the schematic drawing shows

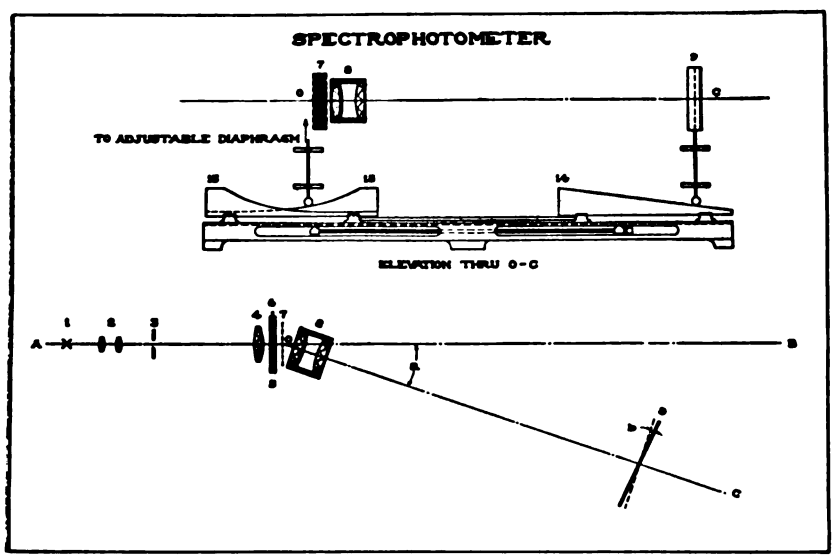

FIG. 6

Diagram illustrating method of moving photographic plate and actuating the intensity-control.

the method used for moving the photographic plate up and down at a constant linear velocity and for opening and closing the sector-diaphragm to obtain a logarithmic increase and decrease of intensity. The cam plates 15 and 14 are driven at constant linear velocity by means of a synchronous motor and carefully cut lead-screw.

In order to utilize the full width of the photographic plate it is advantageous in practice to displace the balance-point *O* so that it lies near one edge of the plate. Then a decrease in the intensity due to the absorber will give balance-points lying between *O* and the upper edge of the plate, Figure 5.

The determination of the point at which density-equality between adjacent strips and curves occurs can be made with great precision by means of a microdensity-comparator designed to isolate a small area on

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each strip near the dividing line. It is unnecessary to make absolute measurements of density since only the position of *density-equality* is of importance. The microdensity-comparator may be either a visual or physical photometer type.

In modifying this method to meet the requirements of solar-radiation-measurement it will probably be necessary to replace the diffraction-grating with a quartz prism and obviously all of the lenses must be made of quartz. Furthermore a standard source must be used in making the comparison-exposure. By setting up the standard source in a suitable position off of the optical axis and by using a total reflecting prism in front of the entrance slit, which can be moved in and out at will, the first series of exposures can be made to the solar radiation and the second to the radiation from the standard source. It is probable that for the region between 450 and 350 μ the grid-plate method as described previously could be used to advantage thus obtaining relative energy determinations throughout an appreciable wave-length band from one exposure. In the region of wave-lengths shorter than 350 where the rate of change of solar intensity with wave-lengths is great it is probable that scattered light will become serious if an attempt is made to determine radiation-intensity over a wave-length band of appreciable extent. Fabry and Buisson [18] used two spectroscopes in tandem in order to obtain monochromatic radiation free from impurities due to scatter in the optical system. This is undoubtedly the best method for obtaining high spectral purity although a fair approximation to satisfactory purity can be had by using extremely narrow monochromatic filters transmitting radiation of the wave-length being measured. In our work (loc. cit.) on the sensitivity of photographic materials in the ultra-violet region we found it quite impossible to obtain sufficient purity by any method except the double monochromatic illuminator. The use of monochromatic filters in this work was almost prohibitive due to the necessity of determining the transmission of the filter itself for the various wave-lengths. In measuring solar radiation, however, if the filter is interposed during exposure both to the sunlight and the comparison-source it will be unnecessary to know the transmission of the filter for the wave-length in question.

By using a monochromatic illuminator to furnish radiation for the spectrophotometer as shown in Figure 6 high spectral purity could be obtained. It would be necessary to dispense with the grid and to make a pair of graded exposures, one using solar radiation and one using the standard source, at each wave-length. In this case the plate-slit, Figure

[18] CHARLES FABRY AND H. BUISSON. Astroph. J. 54: 297 (1921).

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4, would be replaced by a small square opening having a dimension in the direction of dispersion equivalent to a very narrow wave-length band. The result obtained in this way would consist of a single pair of density-strips graded in opposite directions, the position of the balance-point being used to determine the relative intensity of the solar radiation and the comparison source.

The mechanical construction of the instrument necessary for the application of this method could be appreciably simplified by adopting a step by step exposure-method in lieu of the continuous one described. Density measurements made on these would give a sensitometric curve for the solar radiation and for the comparison-source radiation at each wave-length. The point of intersection of the two curves, corresponding to the point of intersection of curves *B* and *C* in Figure 3, would then determine the relative intensity of the two radiations. The photographic plate could be moved by hand or by an automatic mechanism corresponding to the discontinuous changes in the diaphragm-setting. A series of fixed diaphragms of the radial sector-type would probably be better than a set of the variable diameter type since the former would be independent of any zonal aberration present in the optical system. The intensity could with advantage be controlled by using screens made by depositing platinum cathodically on thin plates of quartz. This material is relatively nonselective in the region between 250 and 450 μ as shown by the spectrophotometric density-curve, Figure 7. Such screens can be calibrated by any suitable radiometric or photographic method. Since they are nondiffusing their calibration is not as troublesome as screens made by using developed photographic images. In the case of the latter materials it is essential to calibrate them in the position in which they are to be used in order to be certain that the value of density obtained is equivalent to their effective density-value.

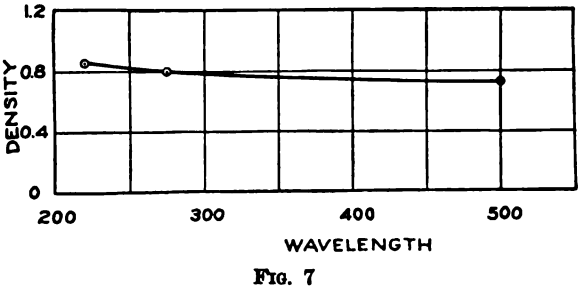

FIG. 7

Spectrophotometric density-curve.

Double monochromatic quartz illuminators are now available commercially, an excellent one being manufactured by Carl Zeiss, Berlin. By the addition to one of these instruments of a suitable set of absorbing diaphragms and a plate-holder at the exit slit of the instrument it

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should be possible to apply the principle of the method outlined above. This consists essentially of making a series of sensitometric exposures to the radiation of unknown intensity and an exactly similar set to a radiation of known intensity, this being done at each wave-length. The sensitometric exposure may be either continuously graduated as in the instrument designed for work in the visual, or discontinuous (step by step) if such is more convenient. In case of the continuous variation in exposure the relative energy will be determined by finding an intensity-balance between the two sensitometric strips, thus eliminating the necessity of making density measurements. In case of the step-by-step method it will be necessary to make density measurements and to plot the resultant density-log E characteristic. The point of intersection between the two characteristic curves thus obtained will determine the required relative intensity-value.

As a comparison-source it is probable that a tungsten-ribbon filament mounted in a quartz bulb is best. Such a source supplied with current from a storage battery and controlled by a potentiometer method should be constant over long periods of time with very high precision. The relative intensity of radiation emitted at various wave-lengths by a tungsten filament at a known temperature can be computed by the well known radiation formula. The constants for tungsten have been determined with high precision. A tungsten filament operating at a temperature of 2,960° K emits sufficient radiation in the region between 290 and 400 μ to serve very satisfactorily as a standard source with which to compare the solar radiation. The tungsten-ribbon filament mounted in a quartz bulb has been used in this laboratory as a standard of radiation in this region in connection with our work on the measurement of photographic sensivity. Using a double monochromatic illuminator of relatively high aperture and ordinary commercial photographic materials exposures down to 300 can be obtained in reasonably short time.

Sensitivity of photographic materials—The sensitivity of photographic materials extends into the far ultra-violet and a little difficulty is experienced in spectrophotometric work in this region in obtaining sufficient sensitivity for practical purposes. As stated previously the gamma in most cases is relatively low at wave-lengths between 2,500 and 3,000 Ångströms, thus resulting in maximum densities which are relatively low. The paper previously mentioned by Harrison [9] gives information relative to the distribution of sensitivity for several well known photographic materials. The same author has also published a paper [14] dealing with the effect of various fluorescent oils on increasing the sensitivity

[14] George R. Harrison. J. O. S. A., 11: 113 (1925).

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of photographic materials to ultra-violet radiation. This procedure may be advantageous in working in the extreme ultra-violet, wave-length shorter than 2,500 μ, but it is not probable that such procedure will be found of any particular advantage in solar radiation-measurements.

In conclusion, it is desired to emphasize again that certain definite conditions should be kept in mind when using photographic materials for making measurements of radiation-intensity. These may be summed up briefly in the statement that in general two radiation-intensities are equal only when for equal times of exposures equal densities are produced, it being assumed that both exposures are non-intermitttent, that the two radiations are of the same wave-length or if heterogeneous are identical in spectral composition, and that the two densities have been produced by identical processing, that is development, fixing, washing, drying, etc. It is preferable that the two densities compared lie immediately adjacent to each other on the same photographic plate in order to minimize possible local variations in sensitivity of the materials.

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Eastman Kodak Company,
Rochester, N. Y.

BLEACHING OF METHYLENE-BLUE-ACETONE-WATER SOLUTIONS BY ULTRA-VIOLET RADIATION

HERBERT H. KIMBALL AND IRVING F. HAND

In response to many requests, the Weather Bureau has made some tests of the reliability of the bleaching of a methylene-blue-acetone-water solution, when exposed to solar radiation, as a measure of the intensity of the ultra-violet component in sunlight. It is understood that this method is employed in England and other countries, and details were obtained from a paper by Webster and others, in the *Lancet* for April 12, 1924.

We have used a stock-solution consisting of 5.8 cc. of a 0.1 per cent methylene-blue stock added to thirty cc. of acetone and made up to one hundred cc. by the addition of distilled water.

Ten tubes of clear fused quartz about six inches long with thin walls and an internal diameter of three mm are filled with even fractional portions of the stock-solution from ten per cent to one hundred per cent to serve as comparison, or color-match tubes. To prevent deterioration of their contents they are sealed and left in a dark-room, as are also the stock-solution and all apparatus used in these tests.

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For measuring ultra-violet light, tubes similar to the comparison tubes are filled with the stock-solution, sealed with beeswax, and exposed in a horizontal position above the roof of the building. The axis of the tube points north and south.

The first exposures showed surprisingly large bleaching effects. So, also, did the stock-solution when exposed in a tube of ordinary glass, which is not supposed to transmit ultra-violet light. This indicated either that the solution was sensitive to light of wave-lengths greater than 3,500 Ångströms, or that the chemicals were impure.

Through the courtesy of Dr. Garby and Mr. Pinck of the Fixed Nitrogen Research Laboratory, Bureau of Soils, our supposedly pure acetone and methylene-blue were submitted to repurifying processes, the former through fractional distillation, the latter first by crystallization in an aqueous salt solution and afterwards dissolved in alcohol, filtered and precipitated by the addition of ether.

It is difficult to obtain pure methylene-blue, as it is not entirely dried out at 105° C, and it begins to decompose at 110° C. For this reason, in any series of measurements the same stock-solution should be used throughout if comparable results are desired.

Using these purified chemicals, the bleaching through the walls of ordinary glass became negligible, while through quartz on most clear days it is a measurable quantity. The measurement consists in matching the color of the solution in the tube that has been exposed to sunlight with the comparison tubes described above. This permits comparison of the bleaching effect on one day with that on another, but does not give measurements of the intensity on any standard scale.

It was pointed out by Webster, in the *Lancet* previously quoted, that the bleaching effect is 0.6 greater with the solution at a temperature of 25° than at a temperature of 15° C. That high temperature accelerates the bleaching has been confirmed by exposing two tubes in a similar manner except that one was kept at a temperature of about 98° F by placing a heating unit under it with a sheet of dark colored asbestos between, while the other was at 50° F, the temperature of the air. Two tests of this kind indicate a bleaching of sixty and eighty per cent in the warmed tubes as compared with forty and fifty per cent in the tubes at air temperature.

The following average values for December 1926 to March 1927, inclusive, show a decided seasonal effect due not only to increased receipt of ultra-violet radiation with increased solar altitude, but also to a temperature-effect. Expressed in percentages, the bleaching for December averaged thirty-eight; for January twenty; February forty-

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eight, and March, twenty-six. In each month the daily exposure was about six hours, commencing at 8 A. M. and was confined to clear days. A few exposures on days with dense clouds showed only a trace of bleaching. The temperature on the days when the tubes were exposed averaged about the same for December and January but were much higher in February and still higher in March. The lowest monthly average, twenty per cent in January, is partially accounted for by average wind-velocities of twenty-six miles per hour on the days when the tubes were exposed. No means are given for April, but during this month complete bleaching frequently takes place between 8 A. M. and noon.

As would be expected, the hours of maximum bleaching occur between 10 A. M. and 2 P. M.

On April 8 the tubes were thoroughly cleaned by heating in an oxygen-hydrogen flame and then carefully refilled. The bleaching on this date, however, was a negative quantity, that is, the solution actually turned a slightly darker blue in color. The reason for this remains unexplained although it is probably due to an impurity of some kind in the solution.

Our results indicate that this method of determining the intensity of ultra-violet in sunlight gives only approximate comparisons from day to day, since they are dependent upon so many factors, such as purity of chemicals, and their temperature, which latter is partly dependent upon wind.

U. S. Weather Bureau,
Washington, D. C.

PRELIMINARY NOTE ON CONCLUSIONS REGARDING THE CONSTITUTION OF THE UPPER ATMOSPHERE INDICATED BY DATA OF RADIO

E. O. HULBURT

The phenomena of the waves of wireless telegraphy have led to very definite information about the ionization in the upper atmosphere. Assuming that the pressures in the upper atmosphere are those of the classical isothermal conductive equilibrium hypothesis of Humphreys, Jeans, etc., with negligible amounts of oxygen, and that the ionization is due to the absorption of the short ultra-violet light of the Sun, the ionization is calculated explicitly and is found to be that required by radio for the day-time. At night, however, due to recombination, calculated in a way apparently correct, the ionization decreases in a manner which seems

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quite contradictory to the facts of radio. This same conclusion is reached whether the upper atmosphere contains hydrogen or not.

Calculation of the types of ionization due to α-particles and β-particles from the Sun and to penetrating radiation are made. Radio evidence seems (at the present moment) to be noncommital as to the extent of the influence of these agencies of ionization.

If the upper atmosphere contains oxygen, all the calculations will be profoundly modified. Cario's recent paper which attributes the auroral line to oxygen, Lindemann's rather vehement answer (Astrophysical Journal, March 1927) to Sparrow's criticism of his meteor-theory, and other fields of evidence, indicate that the constitution and pressures of the upper atmosphere are perhaps not those of the classical calculation.

The attempt is now being made to determine to what other conclusions, if any, the data of radio point.

Naval Research Laboratory,
"Bellevue," Anacostia, D. C.

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SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

(Washington, D. C., April 28, 1927)

SYMPOSIUM ON CORRELATIONS OF VARIOUS RADIO PHENOMENA WITH SOLAR AND TERRESTRIAL MAGNETIC AND ELECTRIC ACTIVITIES

PURPOSE OF SYMPOSIUM

N. H. Heck

A good case could be made for considering radio transmission itself as a geophysical subject and certainly its very evident relations with terrestrial magnetism and atmospheric electricity are an appropriate subject for the American Geophysical Union. It is, therefore, not merely a matter of interest to the members but a duty to consider the progress made in the investigation.

The recent rapid growth of interest in the correlations of various radio phenomena with solar and terrestrial magnetic and electric activities is in part to be ascribed to the fact that perfection of transmitting and receiving apparatus makes it reasonable to assume that interference is to be ascribed to outside phenomena and not to the apparatus. An irreducible minimum is being reached beyond which new methods of attack are necessary and complete understanding of the phenomena involved. Improved apparatus for recording signal-intensity is becoming an important factor in this situation.

The practical importance of the investigation from the commercial and military viewpoint and from that of the public interested in receiving radio programs from distant stations is too obvious to need discussion. There is, however, a special noteworthy example in the world radio longitude-determinations of 1926. Since the apparatus used in this work recorded automatically the distant signals, the interference from various causes was of the greatest importance and added greatly to the time required and the consequent cost of the work.

Since representatives are here from all the organizations interested in this work, I have no intention of reviewing the history, feeling sure that each speaker will introduce such history as may be necessary. It is not inappropriate for me to mention, however, that the Coast and Geodetic Survey has recognized its importance and that for several years the observer in charge of the magnetic observatory at Sitka, Mr. Franklin P. Ulrich, has been studying with the aid of the Signal Corps, U. S. Army, and the U. S. Navy, the relations between aurora, magnetic

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storms, and difficulties in electrical transmission and reception. In the case of radio, his work has been handicapped by variations in transmission and his results have been somewhat inconclusive, but it is certain that in the case of the more marked disturbances his work will prove of value when he has made a sufficiently large accumulation.

The Coast and Geodetic Survey is also furnishing magnetic-observatory results to the various investigators of the subject and it stands ready to do the same for all those interested. Attention is called to the fact that it has observatories in the north, in the tropics, and in the intermediate latitudes. It would be of very great value to carry on atmospheric-electric observations and automatic recording of electric signals at one or more of the observatories.

In conclusion, I wish to quote the closing remarks of Dr. Michael Pupin in his address as retiring president of the American Association for the Advancement of Science at Philadelphia in December, 1926:

"When we speak of electrical communications we usually mean exchange of messages between man and man. But a careful study of the static, of the fading of radio communications, and of the so-called earth-currents in cables will undoubtedly reveal that they are not, as usually believed, disturbances which only annoy the clumsy methods of human operators. They are messages which are far more important to mankind than mere communications between mortals. For instance, I can not help feeling that the so-called earth-currents in cables are messages telling us many secrets which are going on in the Sun, the central power-station which supplies the moving power to all our organic and human activities."

U. S. Coast and Geodetic Survey,
Washington, D. C.

SUNSPOTS AND SOLAR RADIATION

C. G. ABBOT

(Abstract[1])

Pending a thorough revision of all solar-constant observations made at the Smithsonian station at Montezuma, Chile, certain small errors of scale have come to light. Corresponding corrections have been applied to the list of provisional monthly mean observations, 1918 to 1926. A fairly close correlation exists between the variation of the "solar constant of radiation" and the Wolfer sunspot numbers. Higher solar radiation

[1] Complete paper is published as Smithsonian Misc. Collect., vol. 80, no. 2, 1927.

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attends larger sunspot numbers. The relation is not linear. More rapid changes of radiation accompany changes at times of low absolute numbers. At high numbers the change tends to be asymptotic.

Regular periodicities of the solar radiation of 25⅔, 15, and 11 months, and higher harmonics of these periods are found. Of these the 25⅔ month period is much the strongest. It has also long been known in weather phenomena.

Daily observations of solar radiation are going on at Table Mountain, California, Montezuma, Chile, and Mount Brukkaros, Southwest Africa, under the Smithsonian direction. It is hoped that a comparison of their results will yield, within a few years, definite evidence as to the controverted question as to whether or not sunspots at their crossing of the Sun's central meridian tend to be accompanied by a temporary diminution of the solar constant.

Astrophysical Observatory,
Smithsonian Institution,
Washington, D. C.

SUNSPOTS AND MAGNETIC AND ELECTRIC DISTURBANCES

LOUIS A. BAUER

The continued study of the correlations between solar activity and disturbances in the Earth's magnetic and electric condition is of special interest during the present period of increasing sunspottedness. Neither the number, area, nor position of spots on the Sun's visible disk may be taken, however, as a safe index for the prediction of the occurrence of magnetic storms, nor of the production of the electric currents in the Earth's crust which are responsible for interruptions in telegraphy. There have been notable magnetic storms when there were no spots on the Sun's visible disk. The Earth's magnetic activity does not cease during a year of minimum or of almost no sunspottedness.

The desire has therefore arisen for other measures of solar activity which would supplement the information derived from spots and prominences. Possibly continued measurements of the magnetic fields of disturbed areas of the Sun and the information gained with the aid of the spectrohelioscope and the spectrograph will, in the course of time, yield data on which to base new measures. But it may happen also in the end that changes in the Earth's magnetism and electricity, radio transmission and ultra-violet radiation of the Sun, will be our most definite measures of those solar agencies with which we are particularly concerned.

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It will be of interest to record here that a cooperative plan is now in progress between the Mount Wilson Observatory and the Department of Terrestrial Magnetism for the study of solar and magnetic disturbances. A magnetic variometer giving both visual and photographic indications of changes in horizontal intensity has been supplied by the Department and has been in operation at Mount Wilson since last August. The purpose is to indicate to the Mount Wilson observers the times for special intensive study of solar phenomena, with all the means available at the Observatory.

We must give attention to the various measures of magnetic activity before fruitful correlative studies of terrestrial and solar phenomena can be undertaken. Taking, for example, as measures, the well-known magnetic-character numbers, or using numbers indicating the frequencies of magnetic disturbances, it is found that both of these measures show a tendency towards a double periodicity during the year—maxima near the equinoctial months and minima near the solstitial months. The measure known as the inter-diurnal variability of the horizontal intensity, tends to show a similar double periodicity during the year. Generally, the sunspot measures show no such periodicity. Thus the magnetic measures contain effects, due in some manner to the Earth's orbital motion, which require elimination before the correlation with solar phenomena, month to month, week to week, day to day, may be attempted.

Magnetic measures based on the total change in any particular magnetic element during a given period, a day for example, likewise exhibit annual periodicities which, in general, do not correspond with the double periodicity just described. So here again effects of a terrestrial character, unless we are dealing with very severe magnetic storms, must first be eliminated. Time will not permit us to enter into the various methods for eliminating, as far as possible, terrestrial effects.

The year 1920 is of particular interest in connection with the remarks just made. It so happened during that year that the Wolfer monthly mean sunspot-numbers exhibited to some degree a double periodicity, with maxima in March (70.2) and in October (49.6). According to the magnetic-character numbers the maximum disturbance activity apparently occurred in September. Quantitative measures of magnetic disturbance would show, on the other hand, a maximum in March—the month of highest sunspottedness.

In March, 1920, there occurred two notable magnetic storms, namely, March 4 to 5, and March 22 to 23, the second being two and more times severer than the first. Owing to the limited scale, the magnetic-character number assigned to both of these cases is, however, the same, namely, 2.

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We thus see why quantitative and qualitative measures may not agree in their indications and the precautions which must be used in correlative studies.

The correlation between sunspottedness and terrestial magnetism is most pronounced for the periodic magnetic variations. Thus the correlation-coefficient between the annual mean diurnal range and the annual mean sunspot-number (or area) may reach 0.9. For a group of seventy-eight principal magnetic storms registered at the Cheltenham Magnetic Observatory 1913 to 1922, the correlation-coefficient ranged from 0.35 to 0.64, according to the measure of solar activity used. The solar measure, which gave the highest correlation was a quantity derived from the expression, S_p $(1—\rho)$, in which S_p is the Greenwich projected sunspot-area, and is the mean distance of a spot, or group, from the center of the Sun's disk. That is, on the average, the spots near the Sun's center appear to be the most effective, but there are a number of noteworthy exceptions to this general rule.

The correlation-coefficient between sunspottedness and polar lights and that between sunspottedness and earth-current changes are found to be high.

Although the electrical phenomena, of which we have cognizance during brilliant displays of polar lights in high altitudes, show a high correlation with magnetic storms, the same cannot be said with regard to the electrical phenomena in the lower regions of the atmosphere. No pronounced disturbances, in general, occur in atmospheric electricity during severe magnetic storms. The disturbances in atmospheric electricity arising from thunderstorms, for example, are far more definite and pronounced.

If we take, however, only the fine weather days, then we find the probability high that the atmospheric potential-gradient and its diurnal and annual ranges, as also the air-earth current, are subject to sunspot influence. The completion of another cycle of observations at widely-distributed stations, not subject to local disturbing influence, will probably have to be awaited, however, before all the questions as to the precise nature of any solar-activity influence on atmospheric electricity may be definitely settled.

We have as yet insufficient reason to conclude that the high correlation between solar activity and the Earth's magnetic activity indicates a direct association, as cause and effect, of sunspots and magnetic storms. It seems safest at present to assume that both sets of phenomena are effects of one, as yet undiscovered cause, which may simultaneously affect the condition of the entire Sun, or at least of a large portion of it. Thus

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more or less permanent centers of activity on the Sun, which are the true source of the Earth's magnetic disturbances, may also be the cause of sunspot formations in other regions of the Sun.

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Carnegie Institution of Washington,
Washington, D. C.

MAGNETIC OBSERVATIONS AT THE MOUNT WILSON OBSERVATORY

SETH B. NICHOLSON[1]

In August, 1926, a magnetograph was installed at the Mount Wilson Observatory in cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The magnetic variometer and recording device with all the auxiliary equipment were furnished by that Department and its installation was personally supervised by Mr. Fleming.

Only the intensity of the horizontal component is recorded, as the plan is to compare the solar observations made each day with the magnetic records, looking for the type of solar activity which may be directly responsible for particular magnetic disturbances. No statistical study of the number of sunspots and their relation to the mean daily range in H is contemplated. In the thirty-foot pit of the sixty-foot tower telescope another similar magnetic variometer is installed, which can be read at the time of each solar observation. The observer is then aware of the state of the Earth's magnetic field and can make more frequent solar photographs if a magnetic storm is in progress.

The routine solar observations consist of direct photographs of the Sun with a 175-mm image; spectroheliograms, with a 53-mm image of the Sun's disk, using the H_α-line of hydrogen and the $K2$-line of calcium; and prominence spectroheliograms with the K-line of calcium. These routine photographs are supplemented by H_α-spectroheliograms with the 175-mm image showing in detail the regions around active spot groups. A spectrohelioscope is being constructed with which to make still more detailed visual observations of the motions of the hydrogen gas in the neighborhood of spots.

At the 150-foot tower telescope, where the image of the sun is 430 mm in diameter, visual observations of the magnetic polarity and field-strength of each spot are made daily. These observations and the

[1] Read by W. S. Adams.

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heliographic positions of the spots are recorded on a full-sized tracing of the Sun's disk.

In addition to these observations of sunspots, daily measures are made of the intensity of the ultra-violet radiation from the Sun.

It is hoped that these solar observations, when compared with the daily records of terrestrial magnetic activity, may help to solve the problem of how solar activity is responsible for changes in the Earth's magnetic field.

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Pasadena, California.

THE CORRELATION OF RADIO RECEPTION WITH SOLAR ACTIVITY AND TERRESTRIAL MAGNETISM—II

GREENLEAF W. PICKARD

This paper is a continuation of an earlier one[1] on the same subject, in which day-reception at 15-25 kilocycles, night-reception at 1330 kilocycles and night-reception at 8-9 megacycles were compared with sunspot-numbers and magnetic measures. Although in the former paper definite relations were shown, there were also discrepancies, particularly in the relation of sunspots to reception and magnetism. When these three elements were graphically compared over any considerable period, the curves swung alternately in and out of step in an irregular-seeming manner, although preserving in a general way a 27-day period.

It must be confessed at the outset that the relation between individual sunspots, reception, and magnetism is still far from definite. In general it appears that terrestrial elements are most disturbed when the sunspots are large and numerous, and particularly when they face most nearly earthward. But often large spots cross the meridian without either accompanying magnetic disturbances or changes in reception, severe magnetic storms sometimes occur when the only sunspots visible are near the Sun's limbs and reception disturbances are not always accompanied by visible happenings on the solar disc.

Dr. Bauer has said[2] that none of the present measures of the Sun's activity is adequate to explain the occurrence and magnitude of dis-

[1] The correlation of radio reception with solar activity and terrestrial magnetism. Proc. Inst. Radio Eng., 15: (2) February, 1927.

[2] Studies concerning the relation between the activity of the Sun and of the Earth's magnetism. Terr. Mag., 30: (4) December, 1925.

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turbances in the Earth's magnetism; that neither the number, area, nor position of spots on the Sun's visible disc may be taken at present as a safe index for the prediction of the occurrence of magnetic storms. As the result of an examination of radio-reception records extending over nearly twenty years, the author finds this statement also applies to individual cases of reception disturbances. But if a sufficient number of cases are examined statistically, very definite general relations appear, and at the present time it is not an over-statement to say that the major cause of reception disturbance is of solar origin.

Undoubtedly both magnetism and reception are also subject to disturbances which are either not of solar origin, or which at least do not follow solar rotation-periods or the longer swing of the sunspot cycle. Thus, diurnal changes are found in both reception and terrestrial magnetism, and seasonal changes are also well known. A solar eclipse distinctly affects radio reception,[3] and less definitely appears to disturb the Earth's magnetism. There also appear to be relations between certain meteorological elements and reception which are not paralleled by magnetic changes, probably because reception and weather are rather local matters, while terrestrial magnetism is quite literally a world-wide affair.

While reception disturbances of non-solar periods are important and fertile fields for investigation, the present paper must confine itself principally to those magnetic and reception changes associated with the 27-day solar rotation-period, and so these other effects must be here eliminated rather than examined. This has been done by taking a sufficiently long series of observations, dividing this into 27-day periods, and finding the daily means. This operation averages out anything which does not recur in each solar rotation, and as will appear from the figures gives a clearer picture of the interrelation than that presented in the former paper.

Although there is no reason to suppose that the solar centers responsible for terrestrial disturbances are necessarily the sunspots themselves, the evidence is now strong that these centers are at least confined within the same solar zones as the sunspots themselves. If it be assumed that these centers, like the accompanying sunspots, are confined within definite areas for long periods, but shift about within these areas from month to month, some of the discrepancies previously found can be quite simply explained. And even if, as at present appears, the wanderings of the active centers are random affairs, the mean of a number of solar rota-

[3] The effect of the solar eclipse of January 24, 1925, on radio reception. Proc. Inst. Radio Eng., 13: (5) October, 1925.

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tions should show definite terrestrial-disturbance maxima corresponding with the meridian crossing of the centers of the active zones, instead of the somewhat irregularly spaced maxima accompanying the transit of the individual centers.

Before periodic means of sunspot-numbers, magnetic measures or reception observations are made, it is often useful to reduce the numerical values to such a basis that periods of high absolute values will not dominate the means of the entire series. In the present paper this is done by converting the daily values into ratios with a moving mean of

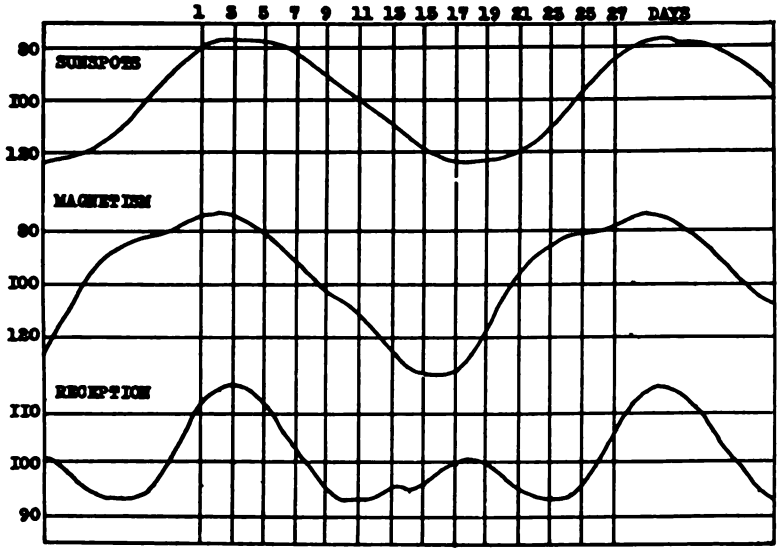

FIG. 1

Mean of twelve solar rotations, October 25, 1908 to September 17, 1909. (Sunspots, magnetic character of day, and maximum night-ranges of "DF" working.)

the period under investigation, thus obtaining a measure of activity within the period.

By taking a sufficient number of periods, even very rough reception-measurements can be made to show definite relations to sunspots and terrestrial magnetism. As an illustration of this, Figure 1 shows a comparison of the maximum nightly ranges of two-way working between station *DF* at Manhattan Beach, New York, and ships at sea,[4] Wolfer final sunspot-numbers and van Dijk's magnetic character-of-day numbers.

[4] ROBERT H. MARRIOTT. Radio range variations. Proc. Inst. Radio Eng., 2: (1) March, 1914.

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The interval taken is from October 25, 1908 to September 17, 1909, corresponding to twelve solar rotations of 27.3 days. The sunspot-curve shows only the fundamental, but the magnetic and to a greater extent the reception curves show the existence of shorter periods. Owing to the extreme roughness of the reception data, no attempt has been made to investigate these shorter periods, although this has been done for some of the later and more accurate reception-measurements. The relation

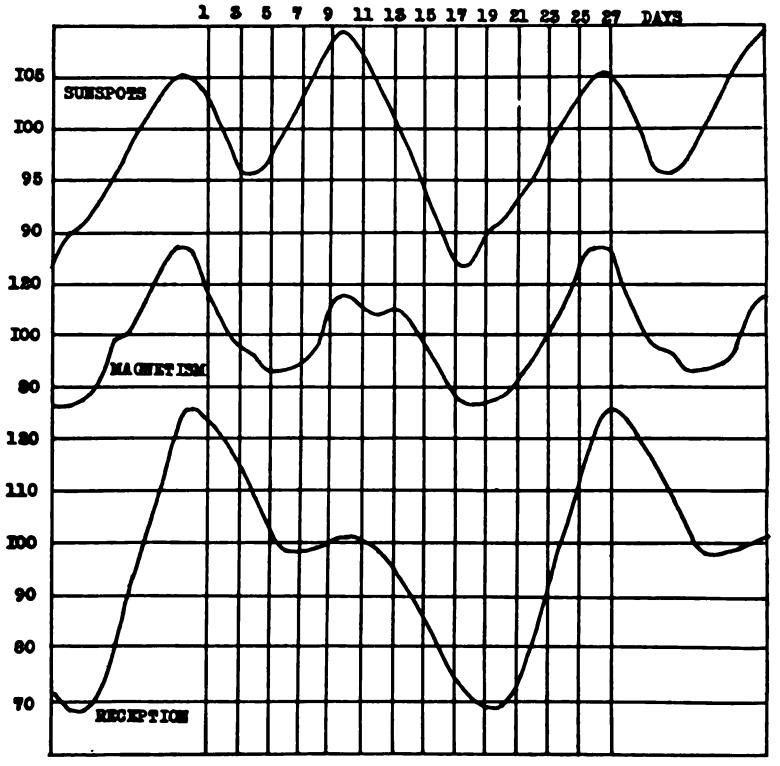

FIG. 2

Mean of five solar rotations, January 14 to May 30, 1917. (Sunspots, magnetic character of day, and Washington day-reception of "POZ.")

of reception to the other elements is inverse, which appears characteristic of night-reception save at ultra-high frequencies. It is of interest to note that this transmission was all at frequencies within the present broadcasting band of 500-1500 kilocycles, so that it may be compared with present-day measurements, allowance being made for the fact that in 1908 to 1909 spark-transmitters of relatively high decrement were used.

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During 1917, a sunspot maximum year, the U. S. Naval Radiotelegraphic Laboratory made audibility meter measurements at Washington of day-reception from station *POZ* at Nauen, Germany. Owing to war conditions, Dr. Austin considers these the least accurate of his long series of measurements of this station; nevertheless Figure 2 clearly shows correlation between this reception, sunspots, and terrestrial magnetism. Unlike the 1908 to 1909 night-reception of the first figure, the day-reception here is directly related to sunspots and magnetism, which seems to be the normal relation of day-reception at low frequency; the 1926 exception to this rule will be discussed later.

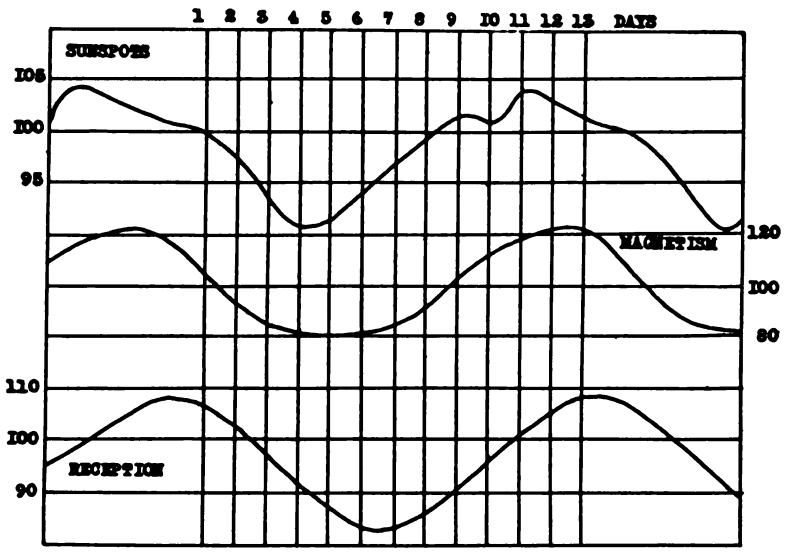

FIG. 3

Mean within five solar rotations of ten 13.64-day periods, January 14 to May 30, 1917.

(Sunspots, magnetic character of day, and Washington day-reception of "POZ.")

All three curves of Figure 2 show shorter periods of considerable amplitude, and despite the roughness of the measurements, an analysis has been attempted for the second harmonic of the solar rotation-period, or 13.6 days. The result is shown in Figure 3, as three nearly sinusoidal and parallel curves. The low amplitude of the sunspot-curve is due to the nature of the sunspot-numbers, which are taken over the entire visible solar disc, or over nearly 180° in solar longitude. This process leaves very little of the shorter or harmonic periods in the sunspot-numbers, although it will be shown later that these are prominent in

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spot-numbers taken in restricted zones, instead of over nearly a hemisphere.

In Figure 4 is shown a comparison of sunspots, terrestrial magnetism, and low-frequency day-reception in 1923, a sunspot-minimum year. The

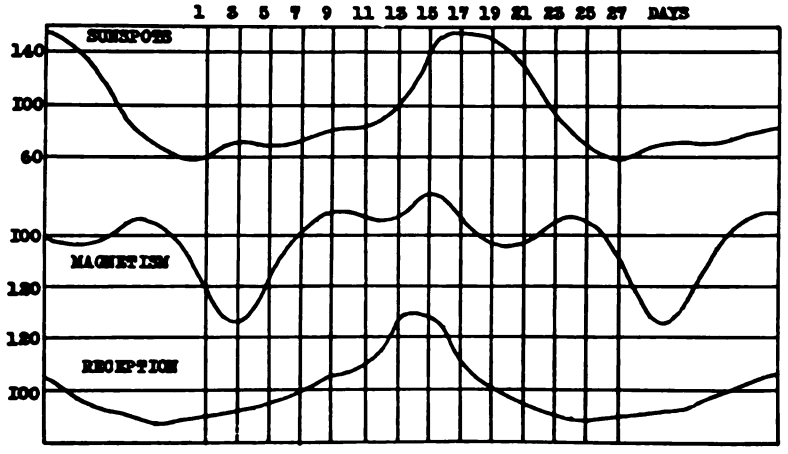

FIG. 4

Mean of seven solar rotations, May 14 to November 21, 1923.
(Sunspots, magnetic character of day, and Washington day-reception of "POZ.")

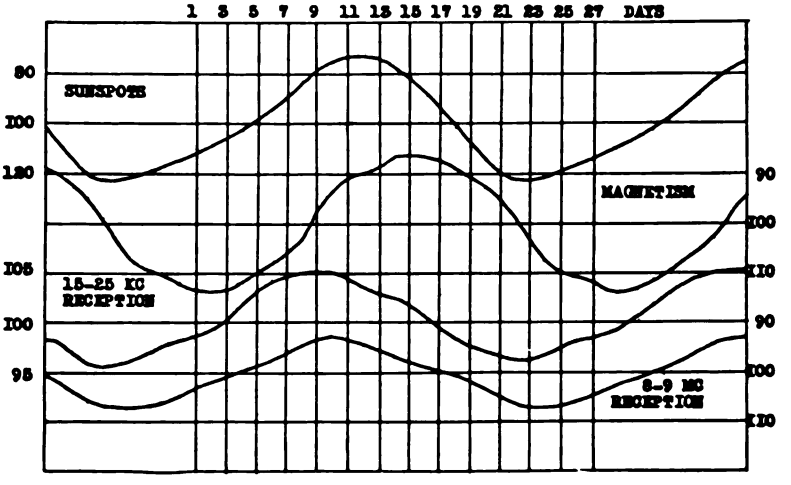

FIG. 5

Mean of eight solar rotations, January 25 to August 31, 1926.
(Sunspots, diurnal range of horizontal intensity at Cheltenham, 15-25 kilocycle day-reception at Washington, and 8-9 megacycle night-reception at Washington.)

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irregularity of the sunspot-curve is in part due to the fact that forty-seven per cent of the days in this interval had a spot-number of zero. Again a direct relation is found between day-reception, solar activity, and magnetism. Very similar results are obtained for day-reception in 1922, 1924, and the first part of 1925. But in the fall of 1925 an inversion commenced, and for at least 1926 day-reception from Nauen was found to be inversely correlated with sunspots within the solar rotation-period.

This 1926 inversion for low-frequency day-reception is not peculiar to the Nauen station. In Figure 5 is shown the 1926 relation between sunspots, magnetism, day-reception for a group of nine stations in the

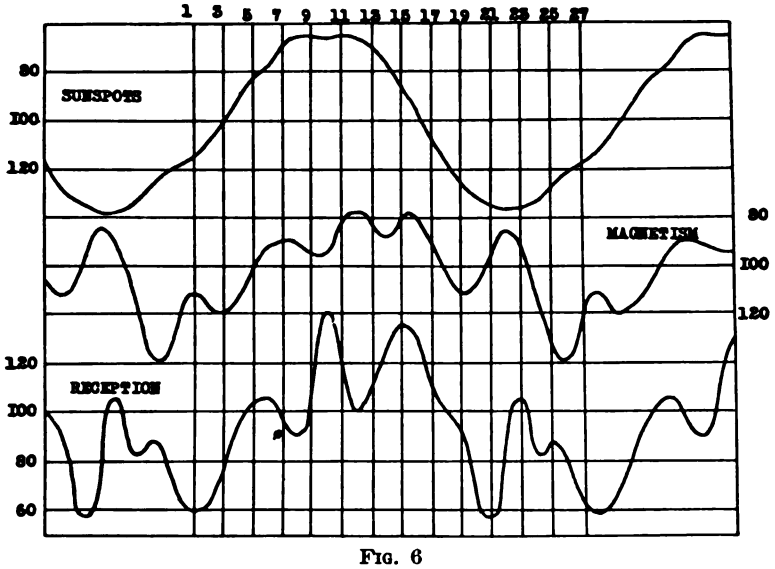

FIG. 6

Mean of eight solar rotations, January 25 to August 31, 1926. (Sunspots, diurnal range of horizontal intensity at Cheltenham, and night-reception at Newton Centre from "WBBM" at Chicago.)

15-25 kilocycle band, and night-reception for seven stations in the 8-9 megacycle band. A close agreement between the two reception-curves is evident, but the sunspot and magnetic curves lag four and six days, respectively, behind reception. The correlation between sunspots, magnetism, and 8-9 megacycle night-reception is direct, but is inverted for the 15-25 kilocycle day-reception.

As set forth in the former paper, it appears that reception in the frequency band of 500-1500 kilocycles shows higher correlation with solar and magnetic disturbances than does any other investigated portion of the radio spectrum, and for that reason the author's measure-

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ments have been largely confined to night broadcast reception. In Figure 6 are given the means within a 27.3-day period of the Wolfer provisional sunspot-numbers, the diurnal range of the Earth's horizontal magnetic field as measured at Cheltenham Observatory, and the mean night-field at Newton Centre, Massachusetts, from station *WBBM* at Chicago, transmitting at 1330 kilocycles over the interval January 25

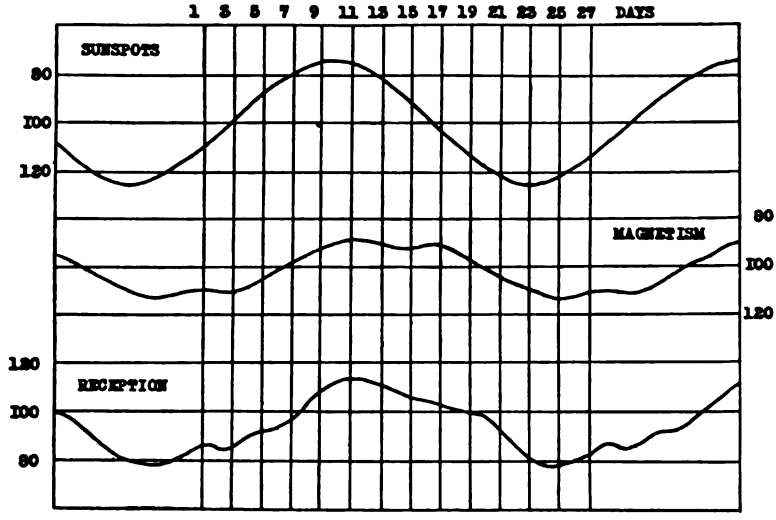

FIG. 7

Mean of eight solar rotations, January 25 to August 31, 1926, smoothed by thirteen-day moving mean.

(Sunspots, diurnal range of horizontal intensity at Cheltenham, and night-reception at Newton Centre from "WBBM" at Chicago.)

to August 31, 1926. While the sunspot-curve is nearly sinusoidal, indicating the absence in the Wolfer numbers of any large amplitude periods shorter than the fundamental, both the magnetic and reception curves obviously contain shorter-period elements. The relations of the fundamental solar rotation-period is brought out in Figure 7 by smoothing with a moving 13-day mean, which largely eliminates the shorter periods.

In Figure 8 periodic daily means are taken within the second harmonic of the solar rotation-period, or 13.6 days. As might be expected, this greatly reduces the amplitude of the sunspot-curve, but reception and magnetism still show shorter period elements. In Figure 9 the third harmonic of 9.1 days is shown, with very small amplitude in the sunspot-curve, but with a marked distortion of the reception-curve, indicating a still shorter-period element. Finally, in Figure 10 the fourth harmonic

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of 6.8 days is shown, with the sunspot-curve reduced to an amplitude of one per cent, and the reception and magnetic curves nearly sinusoidal, indicating that they contain no important shorter-period components.

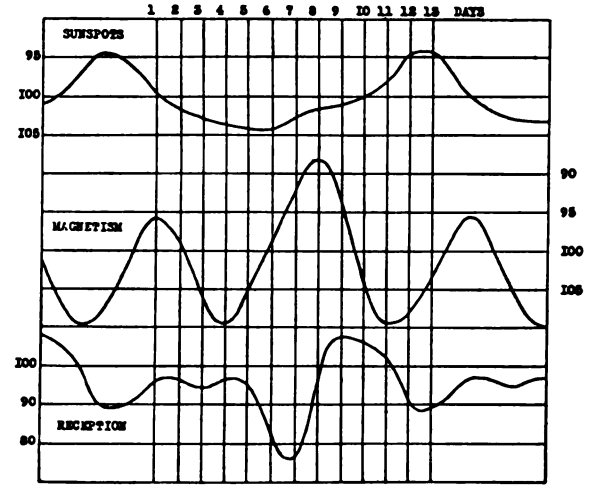

FIG. 8

Mean within eight solar rotations of sixteen 13·64-day periods, January 25 to August 31, 1926. (Sunspots, diurnal range of horizontal intensity at Cheltenham, and night-reception at Newton Centre of "WBBM".)

As indicated above, the Wolfer sunspot-numbers cannot be effectively used in either the investigation of periods shorter than 27 days, or the effect of sunspot-position. Through the kindness of the U. S. Naval Observatory a list has been given of the times of meridian-passage of the larger sunspots of 1926, and a comparison of this with reception shows very clearly that depressions of night-reception are in general coincident with the meridian-transit of the spots, while the appearance of large spots and spot groups near the Sun's limbs have little or no correlation with reception. Through the courtesy of Mr. H. H. Clayton, who has taken daily sunspot-observations for the past several years, sunspot-numbers for a zone ten degrees on each side of the central solar meridian have been furnished for each day of 1926. Using these sunspot-numbers and night-reception from *WBBM*. the relations within the fundamental 27.3-day period, and its second, third, and fourth harmonics are given in Figures 11 and 12. The correlation between the sunspot-numbers for the twenty-degree central zone and reception is very high, and the amplitude of the sunspot-curve for even the fourth harmonic of 6.8 days is quite large. Not only are the sunspot and reception-curves closely alike in form, but they agree in phase to the nearest day, which confirms the conclusion reached from the study of the U. S. Naval Observatory data, that reception-disturbances generally coincide with the earthward presentation of the sunspots.

Measurements of night-static were also taken at 1330 kilocycles, and periodic means made over fourteen solar rotations, from January 25,

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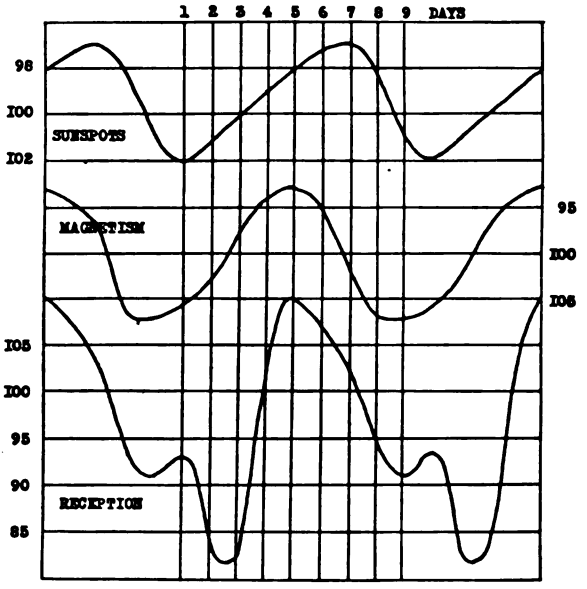

FIG. 9

Mean within eight solar rotations of twenty-four 9.1-day periods. January 25 to August 31, 1926. (Sunspots, diurnal range of horizontal intensity at Cheltenham, and night-reception at Newton Centre of "WBBM".)

shows an inverse relation to sunspots, although the correlation is by no means as definite as that shown in Figure 13 for night-static. At present there is no satisfactory explanation for this interrelation of sunspots, signal, and day and night-static, either on a basis of static-wave transmission, or the assumption of variability in static sources.

In Figure 14 is an example of a double

1926 to February 11, 1927. The result, as compared with sunspots, is shown in Figure 13. Unlike the night-signal at the same frequency, the relation is direct. A similar analysis of night-static in 1908 to 1909[4] at approximately the same frequency gives the same direct relation, which is again the inverse of the night-signal. On the other hand, an investigation of day-static at low frequency over a period of several years

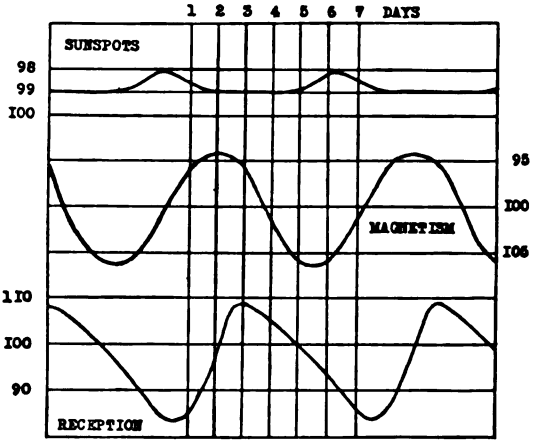

FIG. 10

Mean within eight solar rotations of thirty-two 6.8-day periods, January 25 to August 31, 1926. (Sunspots, diurnal range of horizontal intensity at Cheltenham, and night-reception at Newton Centre of "WBBM".)

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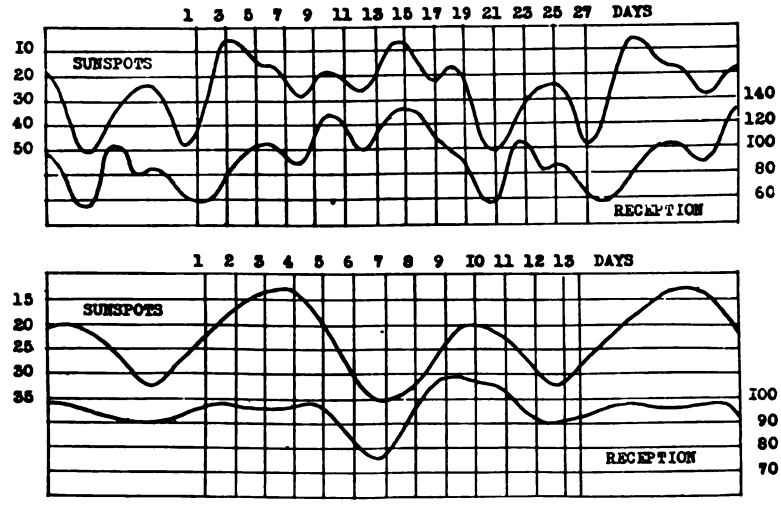

FIG. 11

Mean of eight solar rotations, January 25 to August 31, 1926.
(Sunspots within ten degrees of solar meridian and night-reception of "WBBM" for fundamental and second harmonics of solar rotation.)

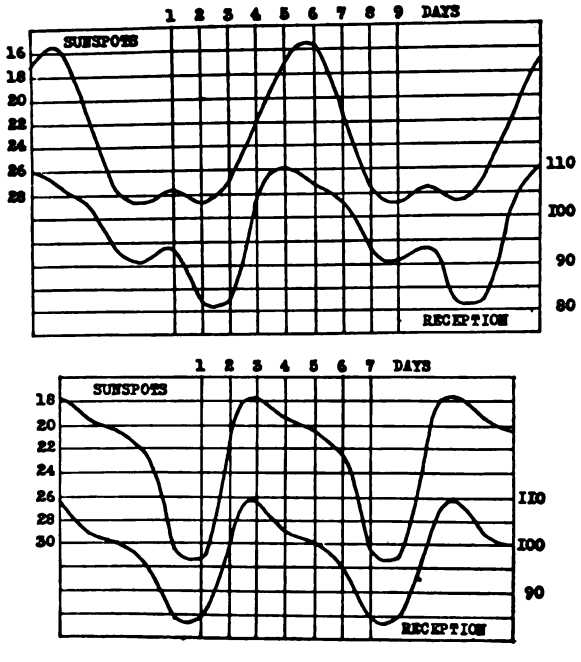

FIG. 12

Mean of eight solar rotations, January 25 to August 31, 1926.

(Sunspots within ten degrees of solar meridian and night-reception of "WBBM" for third and fourth harmonics of solar rotation.)

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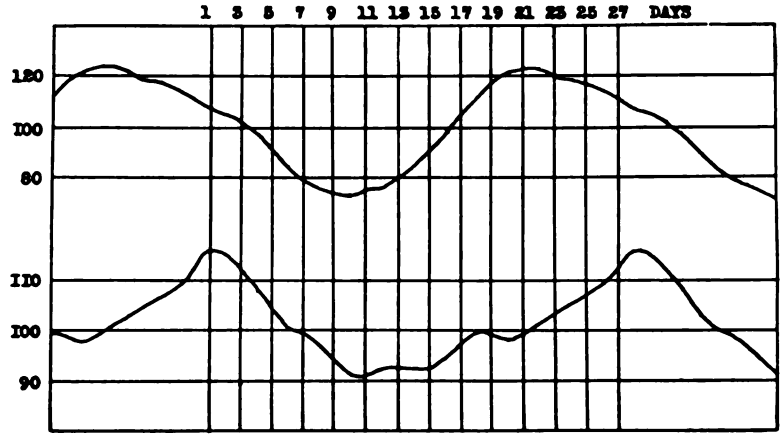

FIG. 13

Mean of fourteen solar rotations, January 25, 1926 to February 11, 1927. (Sunspots and night-static at 1330 kilocycles.)

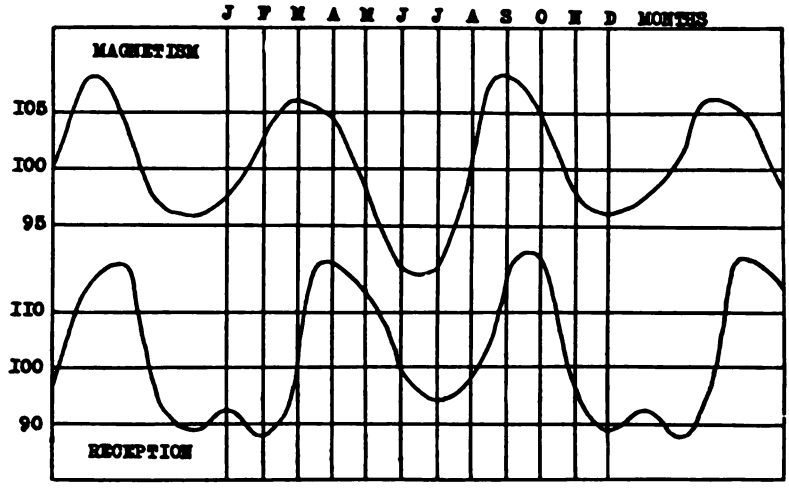

FIG. 14

Mean of eight years, 1916 to 1924, showing monthly averages of magnetic character of day and Washington day-reception from "POZ."

frequency annual period in reception, closely paralleling that already recognized in terrestrial magnetism. Here periodic monthly means have been taken over interval of eight years, from 1916 to 1924, and well-defined maxima show at or near the vernal and autumnal equinoxes. As this is day-reception, the relation with magnetism is direct; if suffi-

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cient data were available to construct a similar graph for night-reception minima would probably be found at the equinoxes. A summation of night spark-reception in 1908 to 1909, scattered observations of broadcast reception in 1923 to 1924, and *WBBM* measurements of 1926 to 1927 does, however, show distinct minima in the spring and fall.

Mr. Clayton has recently found an interesting relation between night-reception of *WBBM* and the number of sunspots in a central zone of 13.3° (the width of a day's travel in solar rotation). When the number of spots in this zone was under ten, the relation between spot-number and reception was inverse; when the spot-number was over twelve, a direct relation was found. This is in accord with the predominant inverse relation which has heretofore been found for night-reception, for in two-thirds of the cases examined for 1926, the sunspot number for the zone was under ten. The relation between sunspot-number in a limited central zone, day- and night-reception, and magnetic measures is now under investigation, and will form the subject matter of a third paper in this series.

Wireless Specialty Apparatus Co.,
Boston, Mass.

RADIO ATMOSPHERIC DISTURBANCES AND SOLAR ACTIVITIES[1]

L. W. AUSTIN

The suggestion that atmospheric disturbances might be due to a bombardment of the Earth's atmosphere by electrified particles from the Sun was first made by De Groot[2] in 1917. A number of years later the U. S. Navy began experiments looking toward the establishment of a connection between these disturbances and solar activity. It was thought that there might be such a connection in the case of the type of atmospherics which sometimes produces simultaneous disturbances in the receiving apparatus at widely separated points as in Honolulu and San Francisco or even in Honolulu or San Francisco and Berlin.[3] There seemed to be some evidence that these simultaneous disturbances took place when large sunspots were in the center of the Sun's disk facing the Earth. The observations were made in San Francisco and in Wash-

[1] Published by permission of the Director of the United States Bureau of Standards.

[2] C. DE GROOT, Proc. Inst. Radio Eng., 5: 75 (1917).

[3] Baumler, Jahrb. d. drahtlosen Teleg., 19: 325 (1922); Proc. Inst. Radio Eng., 14: 765 (1926).

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ington and were continued intermittently for more than a year but without leading to any definite conclusion.

During the past year an examination has been made of the observational material on daylight-disturbances between 9,000 and 20,000 meters wave-length collected by this laboratory since 1918. In the earlier measurements the strength of the atmospherics was determined by the shunt across the telephone at which three crashes could be heard in ten seconds. This was subject to all the general inaccuracies of the shunted telephone method, including the effect of changing observers and possible changes in the sensitiveness of the telephones from time to time. The present method which was adopted in 1924 rates the strength of the disturbances in terms of the measured strength of an artificial signal which is just readable through them. The changes in methods of measurement do not permit comparisons of the earlier and later observations which are of much quantitative value. It seems certain, however, that the daylight-atmospherics at 12,000 meters between 1920 and 1924 were considerably stronger than during 1918 and 1919 and during 1925 and 1926. This would indicate a general negative correlation with sunspots. This is shown in Figure 1. The values before 1924 are dotted to indicate their comparatively low accuracy. Figure 2 shows the deviations of the individual monthly averages from the three-year monthly averages of the 20,000-meter atmospheric disturbances and of the sunspot-numbers from 1924 to 1926. The deviations are used, rather than the monthly averages themselves, in order to eliminate the large seasonal variations of the atmospherics. The increase in the sunspot-numbers with the advancing eleven-year cycle is evident in the figure. The atmospheric-disturbance curve, however, is rather noncommittal, but with some evidence of a negative correlation. The indistinctness of this relationship can be compared with the much more definite correlation of sunspots and signal-intensity, as shown in Figure 3 where the mean values of the daylight signal-strength of several long-wave stations are compared with the sunspot-numbers by the same methods and over the same period of time.

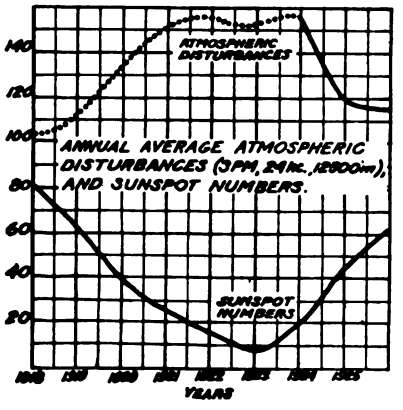

FIG. 1

Annual average atmospheric disturbances and sunspot-numbers.

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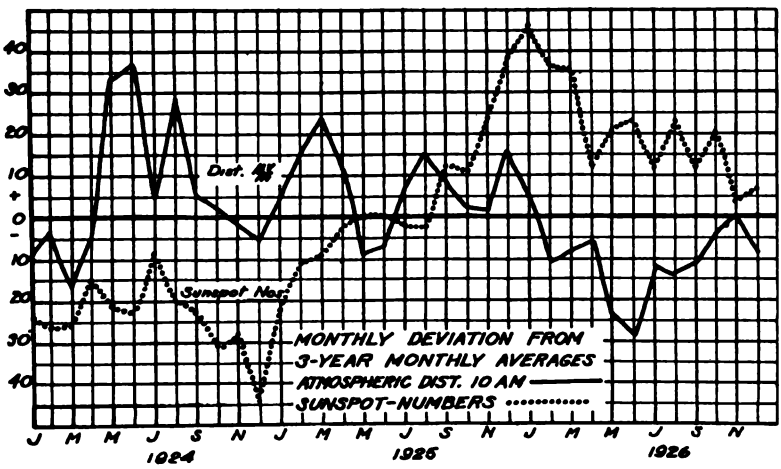

FIG. 2

Monthly deviation from three-year monthly averages for atmospheric disturbances at 10 A. M. and sunspot-numbers.

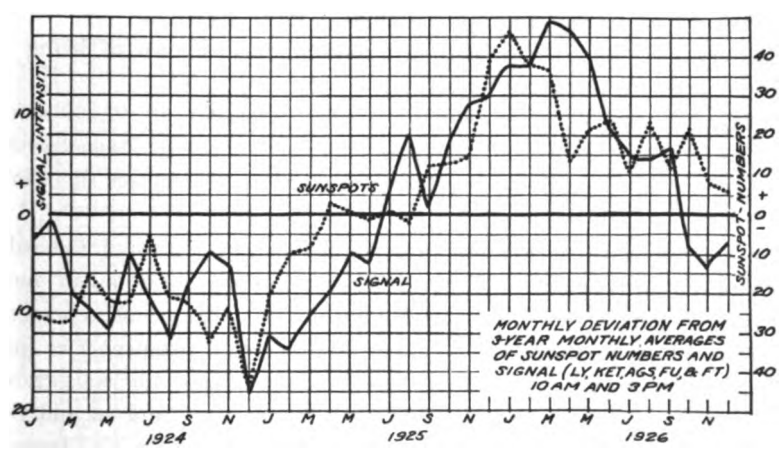

FIG. 3

Monthly deviation from three-year monthly averages of sunspot-numbers and signal-intensity at 10 A. M. and 3 P. M. for stations "LY," "KET," "AGS," "FU," and "FT."

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If the atmospheric disturbances are dependent upon sunspots, it would seem probable that there would be regular changes in disturbance-intensity in the period of the Sun's rotation. Figure 4 shows the twenty-seven-day periodic averages of the 20,000-meter atmospheric disturbances and sunspot-numbers in 1925, the points being repeated during a second twenty-seven-day period for clarity. The disturbance curve is somewhat smoothed by three-day moving averages. It is seen that this curve, while very irregular, shows perhaps some slight evidence of being in nearly opposite phase to the sunspots.

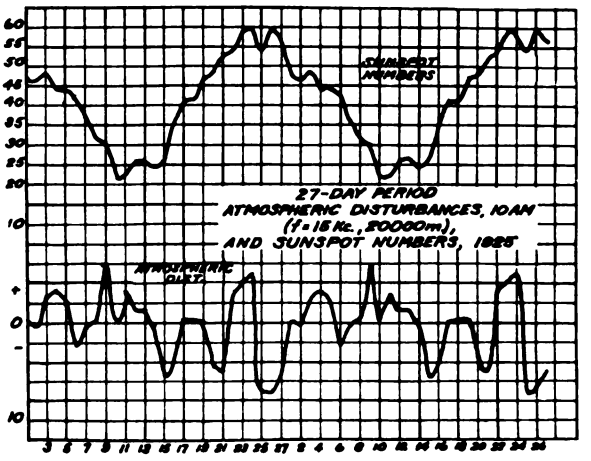

FIG. 4

Twenty-seven-day period of atmospheric disturbances at 10 A. M. (f = 15 Kc., 20,000 m.) and sunspot-numbers for 1925.

Figure 5 shows a comparison of ten-day averages of 20,000-meter atmospheric disturbances and sunspots from January 1 to December 31, 1926. Here the prevailing correlation appears to be also on the whole negative.

For a comparison with these rather indefinite evidences of the solar influence on atmospherics, Figures 6 and 7 show their much more definite connection with terrestrial phenomena. Figure 6 represents the quite close relationship between 20,000-meter atmospherics and local temperature averaged in ten-day periods. Here the well-known parallel variations with seasonal temperature are seen, and in addition there is a remarkable correspondence even in the small peaks and troughs of the two curves. Figure 7 represents the relationship of atmospherics and the number of thunderstorms recorded in a region within approximately two hundred miles of Washington. Here again, as in the case of the temperature, we find a close relationship. The connections shown in Figures 6 and 7 evidently have to do with atmospherics of comparatively local origin. Many of the disturbances are, of course, known to

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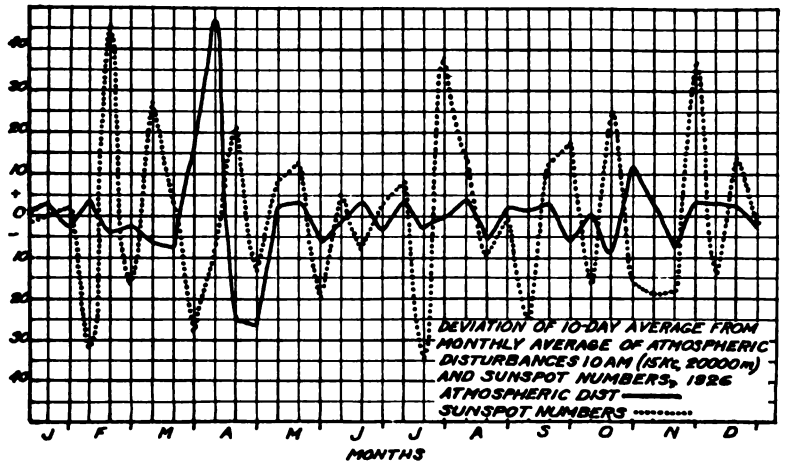
DEVIATION OF 10-DAY AVERAGE FROM MONTHLY AVERAGE OF ATMOSPHERIC DISTURBANCES 10 AM (15Kc, 20000m) AND SUNSPOT NUMBERS, 1926
ATMOSPHERIC DIST
SUNSPOT NUMBERS
J F M A M J J A S O N D
MONTHS

FIG. 5

Deviation of ten-day average from monthly average of atmospheric disturbances at 10 A. M. (f = 15 Kc., 20,000 m.) and sunspot-numbers for 1926

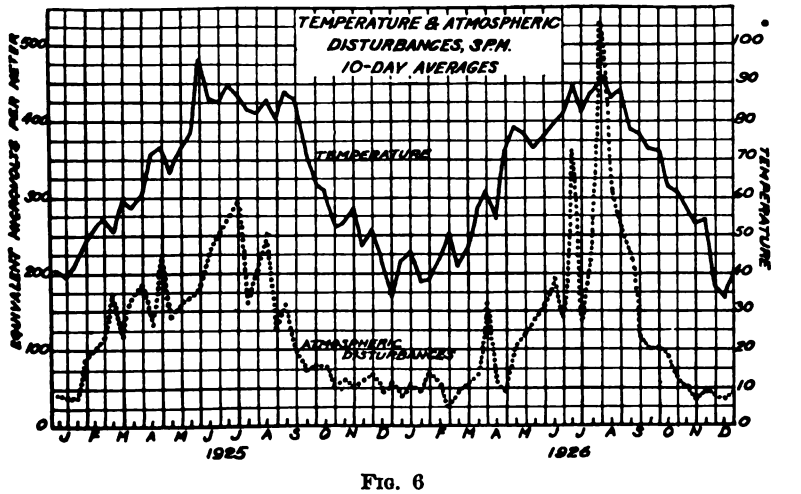

FIG. 6

Ten-day averages of temperature and atmospheric disturbances at 3 P. M. for the years 1925 and 1926.

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come from great distances, but these two figures show how prominent a part relatively local atmospherics play in the difficulties of radio reception in Washington.

In conclusion, although there seems to be some evidence of solar influences on long-wave daylight atmospheric disturbances, at present, the proof seems insufficient to establish this with certainty. It may be that the influence of solar activity on the weather and that of the weather

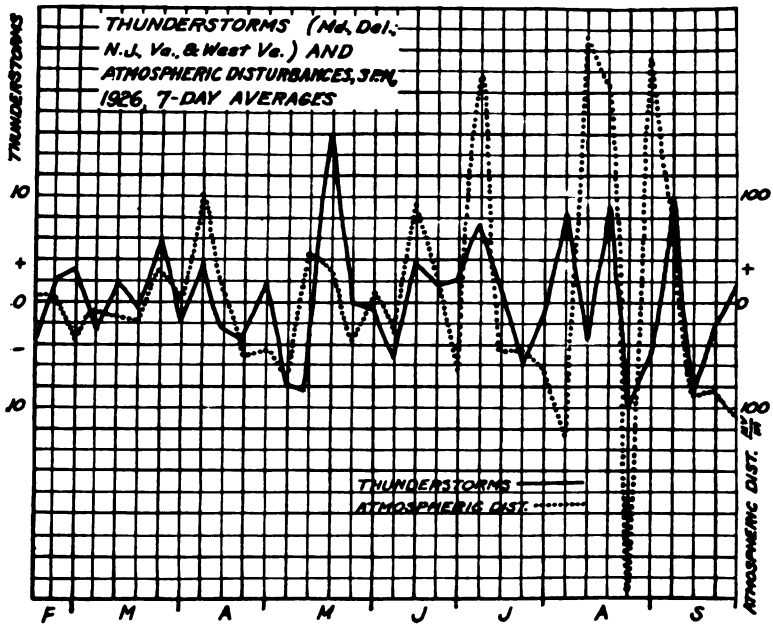

FIG. 7

Seven-day averages of thunderstorms (Maryland, Delaware, New Jersey, Virginia, and West Virginia) and atmospheric disturbances at 3 P. M. for 1926.

on the atmospherics may be the indirect path by which the connection must be traced.

U. S. Bureau of Standards,
Washington, D. C.

A SUGGESTION OF A CONNECTION BETWEEN RADIO FADING AND SMALL FLUCTUATIONS IN THE EARTH'S MAGNETIC FIELD

G. BREIT

The fading of radio signals has been referred to time and again as an interference effect. The suggestion that the upper atmosphere may be

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an important factor in enabling electromagnetic waves to propagate over appreciable distances has been the origin and support of this view. The wave traveling along the ground and the wave arriving by reflection have been supposed to interfere. Within the last few years, however, it has become obvious that more than simple interference is involved. Thus short-wave transmission, i.-e., transmission on wave-lengths below 100 meters in length, showed in the hands of Taylor and Hulburt[1] that beyond a certain range signals are received entirely by an overhead route. In spite of this fact, the signals show fading. Part of this is explained as a general shift in the height of the reflecting layer. However, this can be by no means all, because much of the fading is rapid and does not correspond to the disappearance of the signal in the vicinity of the receiver such as occurs at the skip distance. In fact, the experiments by M. A. Tuve and the writer[2] on reflection of waves from the upper atmosphere showed that fading exists for the reflected waves quite independently of interference with the ground-wave Two suggestions have been made at the time as to a possible cause of the fading. One of them supposed the down-coming wave to be a result of the interference of two or more waves. During a discussion of the subject held at the Department of Terrestrial Magnetism, Dr. A. H. Taylor suggested that the Earth's magnetic field might be the cause of some of the fading. On examining the matter, the writer found that since the upper atmosphere must show magnetic double refraction and since, therefore, there must be in general at least two possible rays between the transmitter and receiver, a change in the interference conditions of these two rays must take place whenever the Earth's magnetic field changes. The change in the relative phase of the two rays turns out to be large even if the Earth's field changes slightly. Several gammas (0.00001 Gauss) may turn the plane of polarization of the ray through 30°. As a result, the vertical component of the electric intensity may be changed from 0 to its maximum value in a field of fifteen gammas. The interference effects here discussed are due to the passage of the ray through an appreciable thickness of ionized air. If the rays are reflected, the interference effects cannot be nearly as pronounced. A study of the magnitude of fading in connection with small fiuctuations in the Earth's field may lead, therefore, to an understanding of the manner in which the ionization increases with the height.

Some simple calculations are given below in order to show how the interference conditions may change. At the same time the effect of a

[1] A. H. Taylor and E. O. Hulburt. Phys. Rev., 27; 189-215 (1926).

[2] G. Breit and M. A. Tuve. Phys. Rev., 28: 554-575 (1926).

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change of frequency and of the ionization are estimated. The calculations do not pretend to be exact. They are intended to show the order of magnitude of the effects.

Before performing the calculations we shall restate the assumptions about the nature of propagation of radio waves which will be used. We suppose the upper atmosphere to be partly ionized into electrons as well as heavier ions. We neglect the effect of heavy ions and consider the effect of electrons alone. The density of free electrons is supposed to increase with the height up to a certain level. The magnetic field of the Earth affects the motion of electrons in the manner discussed by Appleton[3] as well as Nichols and Schelleng.[4] We calculate below the effects on the intensity of received signals due to change in the intensity of the Earth's magnetic field and due to small changes in the frequency of the emitted signals. We suppose that while either change takes place, the degree of ionization is constant. On account of certain mathematical difficulties, an exact solution of the problem does not seem to be worth while at this time. However, for some special limiting cases, exact solutions may be obtained and these can be applied probably with a reasonably small error to calculate the order of magnitude in general.

Letting

$$a = \frac{Ne^2}{\pi m}, \quad \nu_o = \frac{eH}{2\pi m c} \tag{1}$$

where N = number of electrons per cm^3, e = charge of the electron in electrostatic units, m = mass of the electron, H = intensity of the Earth's field. The two velocities of propagation of a beam traveling along H are given by

$$V(\nu) = c\left[1 + \frac{a}{\nu(\nu_o - \nu)}\right]^{-\frac{1}{2}} \tag{2}$$

$$V(\nu) = c\left[1 - \frac{a}{\nu(\nu_o + \nu)}\right]^{-\frac{1}{2}} \tag{3}$$

The first of these corresponds to circular polarization in the right-handed sense, while the second corresponds to circular polarization in the left-handed sense if the sense of propagation of the wave is the same as the sense of direction of H. We consider first an idealized condition in which the rays are approximately following the Earth's magnetic field. We may then use formulas (2) and (3) to calculate the refrac-

[3] E. V. Appleton. Proc. Phys. Soc., London, 37: 22D (1925).

[4] H. W. Nichols and J. C. Schelleng. Bell System Tech. J., 4: 215-234 (1925).

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tion of the rays. Let first the ionization be proportional to the square of the height so that

$$a = by^2$$

The two refractive indices corresponding to (2) and (3) are then

$$\left[1 + \frac{by^2}{\nu\,(\nu_o - \nu)}\right]^{-\frac{1}{2}} \text{ and } \left[1 - \frac{by^2}{\nu\,(\nu_o + \nu)}\right]^{-\frac{1}{2}}$$

Both are of the form $\sqrt{1 - a^2y^2}$

The differential equation of the path is

$$\frac{dy}{\pm\sqrt{\cos^2\theta_o - a^2y^2}} = \frac{dx}{\sin\theta_o} \tag{4}$$

$$\left(a^2 = \frac{b}{\nu\,(\nu_o + \nu)} \text{ or } \frac{b}{\nu\,(\nu - \nu_o)}\right)$$

leading to a solution of the type

$$y = \frac{\cos\theta_o}{a}\sin\frac{ax}{\sin\theta_o} \tag{5}$$

The phase of the wave at any point is $\varphi = \int \frac{2\pi\nu}{V}\,ds$, the integral being taken over the path followed by the ray. If φ changes by π, the interference of the ray with another one of constant phase is changed from constructive to destructive. We are interested, therefore, in the phase-difference $\Delta\varphi$ for the two rays if we are to determine the polarization of the wave at the receiving station. A change in the Earth's field δH produces a change $\delta\Delta\varphi$ in the phase-difference $\Delta\varphi$. If this change $\delta\Delta\varphi = \frac{\pi}{2}$, the direction of polarization of the resultant linear vibration is turned through 90°. We must obtain φ for either ray on the supposition that the position of the receiving and the transmitting stations is kept fixed. If the distance between them be l, formula (5) determines θ_o by

$$\sin\theta_o = \frac{al}{\pi}$$

Now, in general, if μ is the refractive index

$$\varphi = \frac{2\pi\nu}{c}\int \mu ds = \frac{2\pi\nu}{c}\int \sin\theta_o\left(1 + \left(\frac{dy}{dx}\right)^2\right)dx \tag{6}$$

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provided the refractive index varies only with the height and provided it is unity at the surface of the ground. Using (5)

$$\varphi = \frac{2\pi\nu}{c} l \frac{1+\sin^2\theta_o}{2\sin\theta_o} = 2\pi \frac{1+\frac{a^2l^2}{\pi^2}}{2\left(\frac{al}{\pi}\right)} \frac{l}{\lambda} \tag{7}$$

$$\left(\lambda = \frac{c}{\nu} = \text{wave-length}\right)$$

Keeping the range l and the frequency μ fixed, we suppose the Earth's field H to have undergone a variation δH. This changes a^2 on account of a change in ν_o (see (4)). The change in φ due to δa is

$$\delta\varphi = \pi \frac{l}{\lambda} \frac{\frac{a^2l^2}{\pi^2} - 1}{\frac{al}{\pi}} \frac{\delta a}{a} = \pi \frac{l}{\lambda} \frac{A^2l^2 - 1}{Al} \frac{\delta A}{A} \tag{8}$$

Where $\pi A = a$, and

$$\delta\Delta\varphi = \delta(\varphi_2 - \varphi_1) = \pi \frac{l}{\lambda}\left[\frac{A_2l^2 - 1}{A_2l}\frac{\delta A_2}{A_2} - \frac{A_1l^2 - 1}{A_1l}\frac{\delta A_1}{A_1}\right]$$

It follows from (4) that

$$2\frac{\delta a_1}{a_1} = -\frac{\nu_o}{\nu+\nu_o}\frac{\delta\nu_o}{\nu_o}, \quad 2\frac{\delta a_2}{a_2} = \frac{\nu_o}{\nu-\nu_o}\frac{\delta\nu_o}{\nu_o}$$

Remembering also that $H^{-1}\,\delta H = \nu_o^{-1}\,\delta\nu_o$ we have

$$\delta\Delta\varphi = \frac{\pi}{2}\frac{l}{\lambda}\left[\frac{A^2{}_2l^2 - 1}{A_2l}\frac{\nu_o}{\nu-\nu_o} + \frac{A^2{}_1l^2 - 1}{A_1l}\frac{\nu_o}{\nu+\nu_o}\right]\frac{\delta H}{H} \tag{9}$$

Let $l = 0$, then

$$\delta\Delta\varphi = -\frac{\pi}{2}\frac{1}{\lambda}\left[\frac{1}{A_2}\frac{\nu_o}{\nu-\nu_o} + \frac{1}{A_1}\frac{\nu_o}{\nu+\nu_o}\right]\frac{\delta H}{H}$$

The quantity, A_2 may be obtained in this case from the height h to which the wave goes. It is easily shown to be for this case $A_2 = \frac{1}{\pi h}$ so that for zenith reflection

$$\delta(\Delta\varphi) = -\frac{\pi}{2}\cdot\frac{\pi h}{2}\frac{\nu_o}{\nu-\nu_o}\left[1 + \left(\frac{\nu-\nu_o}{\nu+\nu_o}\right)^{\frac{1}{2}}\right]\frac{\delta H}{H} \tag{10}$$

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If $h = 100$ kilometers and $\lambda = 70$ meters, then

$$\frac{\nu_o}{\nu_o - \nu} \cong \frac{1}{2} \text{ and } \delta(\Delta\varphi) \cong -3.8 \times 10^3 \frac{\pi}{2} \frac{\delta H}{H}$$

Hence a change in H by $\frac{1}{3800}$ part of its whole amount would turn the plane of polarization of the downcoming beam through 90°. This would cause very severe fading even at a short distance from the transmitter for a change of 13γ (13 x 10^{-5} Gauss) in the Earth's field. A field one-third of that amount would cause appreciable fading. Variations of that order of magnitude in the Earth's field are very frequent and may, therefore, cause an appreciable amount of fading.

Although formula (10) applies strictly to the case of zenith reflection, it is a good approximation to (9) for considerable ranges because $A_2 l$ becomes equal to unity [for the numbers chosen above] if $l = 300$ kilometers. For one hundred and fifty kilometers (10) is still a reasonable approximation. This suggests a connection with the distance of maximum fading for broadcast wave-lengths. This may be determined in addition to the proportion of ground and reflected waves by the fact that for a certain l, $\delta\Delta\varphi$ in accordance with (9) must vanish. Since in formula (10) the phase-velocities (2), (3) have been used and since these velocities cannot be applied well for short-range transmission, we should expect the fading to be greatest some place between $l = 0$ and $l = 300$ kilometers.

Formula (7) gives also the change in the condition for interference if the magnetic field of the Earth stays constant and the frequency of the signal is changed. Using a^2 as given in (4) we get

$$2\frac{\delta a_2}{a_2} = -\frac{2\nu - \nu_o}{\nu - \nu_o}\frac{\delta\nu}{\nu}, \quad 2\frac{\delta a_1}{a_1} = -\frac{2\nu + \nu_o}{\nu + \nu_o}\frac{\delta\nu}{\nu}$$

and hence

$$\begin{aligned}
\delta\varphi_2 &= \frac{\pi l}{\lambda}\left[\frac{2}{A_2 l} - \frac{A_2^2 l^2 - 1}{2 A_2 l}\frac{\nu_o}{\nu - \nu_o}\right]\frac{\delta\nu}{\nu} \\
\delta\varphi_1 &= \frac{\pi l}{\lambda}\left[\frac{2}{A_1 l} + \frac{A_1^2 l^2 - 1}{2 A_1 l}\frac{\nu_o}{\nu + \nu_o}\right]\frac{\delta\nu}{\nu} \qquad (11) \\
\delta(\varphi_2 - \varphi_1) &= \frac{2\pi l}{\lambda}\left[\frac{1}{A_2 l} - \frac{1}{A_1 l} + \frac{1 - A_2^2 l^2}{4 A_2 l}\frac{\nu_o}{\nu - \nu_o} + \frac{1 - A_1^2 l^2}{4 A_1 l}\frac{\nu_o}{\nu + \nu_o}\right]\delta\nu
\end{aligned}$$

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For short-range transmission this becomes

$$\delta(\varphi_2 - \varphi_1) = \frac{\pi}{2}\frac{\pi h}{\lambda}\left[-4\left(\sqrt{\frac{\nu+\nu_o}{\nu-\nu_o}}-1\right) + \frac{\nu_o}{\nu-\nu_o}\left(1+\sqrt{\frac{\nu-\nu_o}{\nu+\nu_o}}\right)\right]\frac{\delta\nu}{\nu} \tag{12}$$

With λ=70 meters and h=100 kilometers

$$\delta(\varphi_2 - \varphi_1) = \frac{\pi}{2} \times 1400\frac{\delta\nu}{\nu}$$

Hence if

$$\frac{\delta\nu}{\nu} = \frac{1}{1400}$$

the direction of polarization is rotated through 90°. This corresponds to a frequency change of 3,000 cycles per second. Hence even a frequency change of 1,000 should produce an appreciable effect on the intensity of the received signal.

Finally, we estimate for the above case the change in φ_2—φ_1 which is produced by a change of ionization. We find in a way quite similar to that just used that

$$\delta(\varphi_2 - \varphi_1) = \frac{\pi}{2}\frac{l}{\lambda}\left[\frac{A^2_2 l^2 - 1}{A_2 l} - \frac{A^2_1 l^2 - 1}{A_1 l}\right]\frac{\delta N}{N} \tag{13}$$

where δN is the change in the number of electrons per unit volume. For short-range transmission this becomes

$$\delta(\varphi_2 - \varphi_1) = -\frac{\pi}{2}\cdot\frac{\pi h}{\lambda}\left(-1+\sqrt{\frac{\nu+\nu_o}{\nu-\nu_o}}\right)\frac{\delta N}{N} \tag{14}$$

With the numbers used above, a rotation through 90° is produced if $\frac{\delta N}{N} = \frac{1}{1800}$. Since changes in the ionization are presumably responsible for changes in the Earth's field, it is reasonable to suppose that (9) and (14) should be combined in any actual case in order to give the resultant change.

In the above we have constantly referred to the short wave-length region ($\nu > \nu_o$). If the wave-length is long, i. e., if $\nu < \nu_o$, only the ray defined by (3) returns to the Earth. If this ray interferes with the ground, wave effects quite similar to those just discussed are produced. Formulas (9), (11), (13) must be modified, however, by omitting the terms in A_2. The order of magnitude of the effects is still the same.

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Even though $\delta\ (\varphi_2 - \varphi_1)$ is the same for a considerable range according to (9), (11), (13), the fading produced may vary considerably over that range. Thus the value of $\varphi_2 - \varphi_1$ is very important because it determines whether the electric vector of the downcoming wave is horizontal or not. The same fluctuation of H may produce, therefore, a reenforcement of the signal in one place and a diminution in another.

Small frequency changes are, of course, known to produce an effect on the intensity of the received signal. It is also known that interrupted continuous waves show less fading on short-wave lengths than continuous waves.[5] It is somewhat difficult to point out definitely what has been happening in the experiments just mentioned. For short wavelengths, however, it seems certain that the fading must be entirely due to the condition of the wave returned by the upper atmosphere. The high "resolving power" of the interference apparatus in that case demonstrates a behavior similar to the one discussed above. It cannot be interpreted on the basis of interference with the ground wave. It must be also remembered that experiments by Tuve and the writer (l. c.) showed that the reflected wave shows fading which is sufficiently great to explain an appreciable amount of the general fading.

The influence of magnetic storms on transmission has given opportunity for considerable discussion. However, it would be dangerous to maintain that the simple calculations given above explain the effects observed. Presumably magnetic storms are accompanied by large changes in the ionization of the reflecting layer. A complete explanation must, therefore, be based on formulas corresponding to both (9) and (13).

SUMMARY

The state of polarization of a radio wave returned by the reflecting layer is studied as a function of (*a*) small changes in the intensity of the Earth's magnetic field, (*b*) small changes in the frequency of the wave, and (*c*) small changes in the ionization of the atmosphere.

It is shown that for the special electron-distribution considered appreciable effects on the intensity of the signal are to be expected for fluctuations in the Earth's field of the order of five gammas, for changes in the frequency of the order of 1,000 cycles, and for changes in the ionization of the order of one part in 5,000. [The number applies to λ=seventy meters.]

[5] R. Bown, Del. K. Martin, and R. K. Potter. Bell System Tech. J., 5: 143-213 (1926); E. V. Appleton and M. A. F. Barnett, Proc. R. Soc., London, 109: 621-641 (1925); G. W. Pickard, Proc. Inst. Radio Eng., 12: (2), 1924.

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The dependence of fading on range indicates that there is a certain range of maximum fading which is of the general order of one hundred miles.

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CORRELATION OF STATIC WITH THE ATMOSPHERE

E. H. KINCAID

The writer has had opportunity at sea to study static with relation to the atmosphere since the spring of 1924 on board the U. S. S. *Kittery*. During 1926, these observations were made with the assistance of the radio compass. The research originally started on board the U. S. S. *Kittery* is now being continued by the Hydrographic Office, Navy Department, in collaboration with the Bureau of Engineering, Naval Communications, and the Bureau of Aeronautics.

The purpose of this article is primarily to show that static has sufficiently definite relationship to the distribution of the atmosphere as plotted on the daily weather map to enable one by proper observations to make use of static in weather forecasting, and to make use of our present knowledge of atmospheric distribution and movement in static forecasting.

This problem must be considered from two different viewpoints. The first is by making use of instantaneous static intensities without reference to any directional properties that static may have. This might be called plotting the Highs and Lows of static such as we now plot Highs and Lows of barometric pressure. The first experiment conducted by the U. S. S. *Kittery* for the Navy Department before the introduction of the direction finder was on this principle.

Considering that a definite relationship is established between atmospheric structure or changing structure and static, facts ascertainable concerning static from one or more points will be of value in forecasting weather; and our knowledge concerning development and movement of atmospheric conditions will assist in making static forecasts. Add to this knowledge what directional properties static is found to have and we begin to realize the possibility of the value of a static observation to a condition remote from the station making the observation. It is this latter feature that will prove of greatest advantage to the mariner.

Two examples are given herewith of well-known meteorological conditions with contrasting types of pressure-distribution. One is a well-

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formed homogeneous High which covers the West Indies, the South Atlantic and East Gulf States, and the ocean-area adjacent thereto.

Figure 1 illustrates the static free and excellent communication-conditions attending this High. The ship at the time off Cape Haytien, Haiti, on March 16, 1927, with a two-kilowatt set had no difficulty in

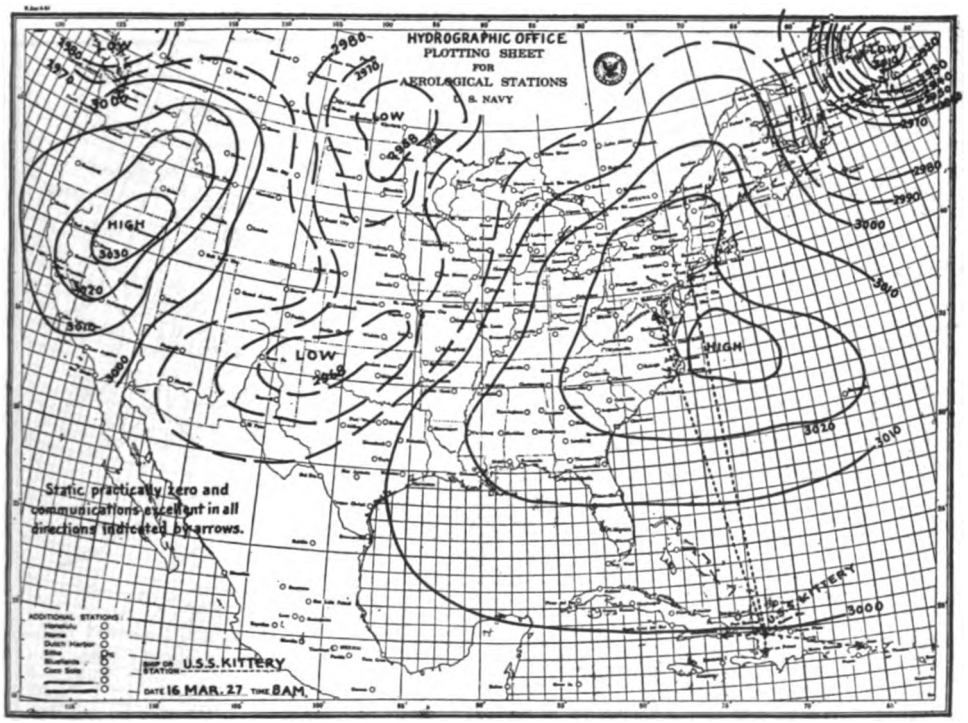

Fig. 1

Communication-conditions and isobars, March 16, 1927, at 8 A. M.

communicating with Port au Prince, Haiti, Guantanamo, Cuba, San Juan, Porto Rico, Arlington, and New York.

Figure 2, the other example, is of the same geographical area, but with a hurricane, the most intense type of Low (save tornadoes) occupying a part of the same area. The Low in this case is the historical Miami Hurricane shortly after it had passed over and devastated Turks Island. The position of the observer was the same during the observance of both state of weather and attendant radio reception-conditions, that is, off Cape Haytien, Haiti, in this case on the evening of September 16, 1926.

In the former, the High, static was practically zero and reception excellent in all directions over long ranges within the High. In the latter,

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the Low or Miami Hurricane, reception was impossible although attempts were made to communiciate with all stations indicated by arrows in Figure 2, namely, Arlington, San Juan, Guantanamo, Port au Prince, and even Cape Haytien, Haiti, which was only forty miles distant.

Our steering gear broke here as we were entering Tortuga Channel to obtain a better lee, and had an *SOS* been necessary, it would have been

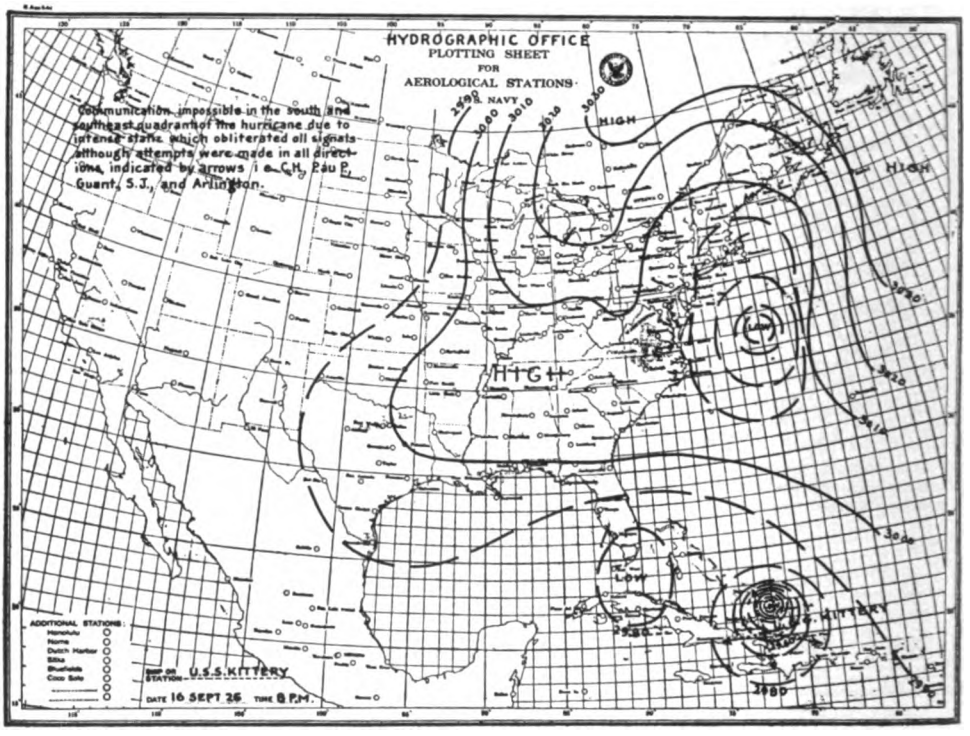

FIG. 2

Communication-conditions and isobars, September 16, 1926, at 8 P. M.

drowned out by the intensity of the static. Fortunately, the U. S. S. *Kittery* is a twin-screw ship, and we used our engines until the steering gear was repaired.

Here we deal not with theory but with facts, namely, (1) that on one occasion static was terrific and the observer was within the 29.60-isobar southeast quadrant of a hurricane, and (2) on the other occasion the observer was within a homogeneous High and static was practically nil. The writer wishes to ask what this and similar phenomena would seem to indicate. To the observer in this case the same relative situations have recurred so often that he is of the opinion that Highs are relatively

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static free and Lows are attended with static somewhat proportional to the intensity of the disturbance. This seems to hold good from troughs of low pressure to hurricanes and from poorly defined Highs with mild static to great homogeneous Highs with practically no static. This High had traveled across the United States from the Pacific States where it was central on March 11. We have every reason to believe that the same relative good reception-condition had identical motion of translation. The rate of the motion of translation of Highs is shown in many publications of the U. S. Weather Bureau and authors of meteorological works (see Figure 3). With the same accuracy as Highs are now used in weather forecasting they can be used in forecasting the negative information concerning static conditions. The Low, or Miami Hurricane, had traveled at the rate of about three hundred miles per day from the doldrums well out to the eastward of the Lesser Antilles, possibly near the Cape Verde Islands. It is a certainty that this area of heavy static and impossible communication-conditions had traveled at the same relative position to the hurricane and at the same rate of three hundred miles per day.

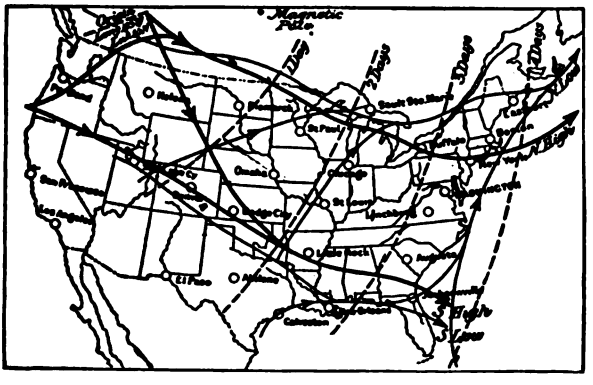

FIG. 3

The Bigelow system of storm-tracks across the United States.

Considering that these things are true and that Highs and Lows and our knowledge concerning their development, disintegration, and motion of translation is to be the basis for our static forecasting, we need next to study the structure of Highs and Lows with a view to locating that part of each which may under the most general conditions be expected to give the greater amount of static. We also want to know where within the High and Low to expect the minimum amount of static for that particular structure. In the Miami Hurricane, static was stronger in the southeast quadrant than in the west and southwest quadrants. In general, the eastern half of Lows will be more heavy in static than the western; the southeast, in general, than the northeast, and the southwest, than the northwest. On March 21 when the High mentioned above had

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moved to the eastward until the *Kittery's* position was in the southwest quadrant, static increased steadily.

In Highs it has been my observation that the center has the mildest static, the southeast quadrant less than the southwest, the northeast less than the northwest; especially is this true near the edge of the structure. Highs of different origin and hence different structure will have different static conditions associated with them. A Pacific High deep but of limited area will have a different static association from an Alberta High which is shallow but of great magnitude. And similarly Lows of different origin will have correspondingly different static attendant thereto.

The foregoing facts can be reconciled with results obtained by many who are studying static with the view of correlating it with the atmosphere. A few observations of others who have studied this subject abroad may be added here:

ABSTRACTS OF PAPERS ON THE METEOROLOGICAL RELATIONS OF ATMOSPHERICS

"In June, 1923, the Council received a letter from Mr. R. L. Latchem, of the cable steamer *John W. Mackay*, Nova Scotia, calling attention to the possibility of using, for the purpose of weather forecasting, observations of the character of those naturally occurring electro-magnetic waves, called atmospherics, which are so familiar to all wireless listeners. The Council appointed a small committee to consider whether observations on atmospherics might be of service in forecasting. As a preliminary to the work of the committee, the writer undertook to prepare the bibliography of the meteorological relations of atmospherics which is now reproduced here.

"The correlation between the occurrence of actual thunder or lightning and the radiation of atmospherics is so well known that many references to it have been omitted, but it is believed that no other well-authenticated data have been overlooked.

"It will be seen that very acute divergences of opinion exist as to possible relations between the intensity of atmospherics on the one hand and most of the phenomena definitely recognized as 'meteorological' on the other. There is an overwhelming consensus in favor of the obvious correlation with thunder, moderate agreement on the correlation with convective processes in the absence of reported thunder, but beyond this point the evidence is mutually contradictory. Reasons for this are not difficult to assign. It is established beyond doubt that the range of reception of atmospherics may reach one or two thousand miles; it is most probable that the range frequently, if not usually, attains the length of the Earth's semi-circumference. Comparisons between received atmospherics and local weather will therefore,

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in part, be a comparison of the weather of a parish with the electrical phenomena of a hemisphere. Moreover it is still impossible to find a scale and a classification for the intensity and character of atmospherics which shall be generally acceptable, unambiguous, and capable of assessment by the average observer. The Beaufort of atmospherics is not yet.

"Nevertheless, the evidence that the atmospheric was well, if rashly, named is accumulating rapidly, and the summaries of the most recent work show that the location of 'cold fronts' by radiotelegraphic observations on atmospherics is an established possibility.

R. A. W. W."

JACKSON, H. B.—London, Proc. R. Soc., 70 (A), 1902, p. 266.

After describing typical *X*-effects from lightning, remarks that *X*'s are more frequent in summer and autumn than in winter and spring, near high mountains than in open sea, in south than in north winds (in the Mediterranean), in the front of a cyclonic disturbance than in the rear, with falling barometer than with rising barometer.

Notes case of a heavy winter-gale, without observed lightning, which was preceded by *X*-disturbance.

CRAWLEY, C. G.—London, Elect., 69, Jan. 31, 1913.

X's in Mediterranean are worst when pressure is low, temperature high, and humidity low. The sirocco forms an exception to this rule, as it always brings atmospherics.

ERSKINE-MURRAY, J.—London, Elect., 67, 1911, p. 219.

Describes observations showing that every observed lightning-flash produces an *X*, multiple flashes producing multiple *X*'s, and discusses the adequacy of the known thunderstorm distribution to account for all *X*-disturbance. The author proposes direction-finding for the location of *X*-sources.

FLAJOLET—Paris, C.-R. Acad. Sci., 154, 1912, p. 729.

Describes the recording of thunderstorms up to 500-kilometer distance by crystal detector and galvanometer.

FRANCK-DUBOQUIER.—Nature, Paris, 41 (1), 1913, p. 218.

On the basis of one year's observations at Anche (Indre et Loire) the relations between *X*'s and weather are thus enunciated (the original French descriptions being retained to avoid ambiguity by loss of onomatopoeia).

(1) Violent "craquements" indicate a thunderstorm, approaching if the *X*'s become more and more frequent, receding if they become less frequent or less strong.

(2) A slight "sifflement" is produced by a heavy hailstorm passing near the receiver.

(3) Dry, isolated, and rather weak "claquements" generally precede a fall of temperature, a spring frost.

(4) If the wind is about to turn, the *X*'s are of short wave-length, and seem to come in strings.

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(5) Numerous "crepitements," accompanied by fairly regular, strong and "fusant craquements," precede great barometric depressions and foretell gales.

LUTZE.—Phys. Zeit., Leipzig, 14, 1913, p. 1194.

Finds that X's and changes of recorded potential-gradient go together. Balloon-observations show great increase of X's inside cloud, and a rapid decrease of X's with increasing height.

DELVAL.—Quoted in Perrett Maisonneuve's "La T. S. F. et la Loi" (1914).

Observations at Mt. St. Aubert, Tournai, May to September, 1912, led to the following conclusions: Absence of X's characterizes approach of fine weather; little precipitate cracklings—hail or heavy rain; distant cracklings—fine weather; numerous and prolonged cracklings—stormy weather; prolonged sound like water from a gutter—sudden change of weather; prolonged and singing sound seeming distant at first, approaching little by little till strong—violent thunderstorm or tempest.

MARRIOTT, R. H.—Proc. Inst. Radio Eng., New York, 2, 1914, p. 37.

An outburst of X's follows a sudden change of wind on the North Atlantic coast of the United States, especially a change from south to north. X's also accompany a rise of temperature there.

RADIOTELEGRAPHIC INVESTIGATIONS COMMITTEE OF THE BRITISH ASSOCIATION.—London, Rep. Brit. Ass., 1915.

X-storms coincide with convective weather, rapid fluctuations of pressure, and rapid movements of depressions.

In Malta, X's precede by several days the advent of convective weather.

In Australia, day-time rain is preceded by X's in 80 per cent of all cases.

In Ireland X's are bad with a northwest wind on the Atlantic coasts.

In Sierra Leone the periodic dry wind suppresses X's.

GOLDSCHMIDT, R.—"La Telegraphie sans Fils au Congo Belge" (Brussels, 1920).

From observations in the Belgian Congo, 1915 to 1917, the author believes that X's from lightning have an effective range not exceeding 100 or 200 kilometers.

In general a day of thunderstorm is preceded by several days of increased X-disturbance.

In general a day of thunderstorm is followed by several days of reduced X-disturbance. This law is more general than the former.

WIEDENHOFF, S.—Jahrb. drahtl. Telegraph., Berlin, 18, 1921, p. 242.

Low X-intensity is found under rainless cloud, X's increase as cloud begins to break up or as rain begins. Diminishing convection-current goes with low X-intensity.

From a comparison of annual variation-curves the author summarises as follows: X-maxima go with low potential-gradient, but high convection-current and high numbers of ions per cc., and conversely for X-minima.

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From diurnal-variation curves: *X*'s are bad when the vapor-pressure is at a maximum at the surface and increasing above, when the conductivity at ground and aloft is increasing, and the surface wind decreasing. *X*-disturbance is at a minimum with maximum conductivity at a moderate height, with overcast sky, with maximum relative humidity, minimum temperature, and maximum air-pressure.

MARCHAND, H.—Rev. Gen. Sci., Paris, 32, 1921, p. 594.

Increased *X*-frequency indicates an imminent thunderstorm; if the intensity of *X*'s is great the thunderstorm will be violent, with wind and rain; if the *X*-intensity remains low the thunderstorm is feeble. If the intensity augments the storm is approaching, and vice versa.

This diagnosis is valid at great distances, before the cloud associated with the storm has appeared at the receiving station.

ROTHE, E.—Paris, C.-R., Acad. Sci., 175, 1921, p. 840.

Infrequent but sustained *X*'s with an intense high metallic note are due to more or less distant cloud. Visible lightning, and hail, give this type of *X*.

Lacoste (q. v.) is summarised.

LACOSTE, J.—Paris, C.-R., Acad. Sci., 175, 1921, p. 843.

Enunciates laws based on radiogoniometric observations at Strasbourg.

(1) If a distinct well-developed depression exists, with closed concentric isobars, the maximum *X*-disturbance proceeds from the south or southeast of the depression, the displacement in direction and variation of intensity allow of following the course of the depression.

(2) If the depression has a distant centre and less curvature, the *X*-maximum is still south or southeast of the periphery, but is less sharply marked.

(3) Secondary depressions, with "barometric pockets" and cols, correspond to storm-fronts, the direction of *X*-maximum is difficult to find, and *X*'s are violent from all azimuths.

(4) A near thunderstorm gives violent *X*'s from its azimuth.

Many *X*'s received in clear weather are comparable in intensity to those of observed lightning. The author concludes that *X*'s are due to more or less distant storm-phenomena, and are often produced in overcast regions.

The last few days' work in the period in question indicates that fog facilitates *X*-transmission.

ROTHE, E.—Ann. Phys., Paris, 17, 1921, p. 385.

X's come from definite azimuths when storm-clouds are distant, but are observed on all azimuths when the storm is very near.

Storm-clouds produce *X*'s which gradually cease as soon as uniform rain starts, but *X*'s persist to some extent when rain is violent.

Strato-cumulus most often furnish well-defined and oriented rumbling *X*'s.

Re-summarises Lacoste (q. v.).

LACOSTE, J.—Paris, C. R. Acad. Sci., 176, 1922, p. 707.

Describes further work at Strasbourg in summer of 1922, confirming previous conclusions, and demonstrating possibility of forecasting new depres-

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sions. Remarks on the special value of the radiogoniometer in thunderstorm-forecasting.

Some thunderstorms give *X*'s which are numerous only on short-wave observations.

WATSON WATT, R. A.—Nature, London, 1922, p. 680.

Preliminary results of directional observations on atmospherics during 1916 to 1918, by stations on British coasts, show that on an average five apparent sources of atmospherics per week were located. Of those checked against meteorological data, fifteen per cent agreed with reported thunderstorms, ten per cent with squall phenomena, sixty-nine per cent with rainfall within the twenty-four hours containing the time of observation, without reported thunderstorms or squalls. Thus ninety-four per cent of the apparent sources were associated with rainfall. Thirty-five per cent of the cases examined fell on the forward edge of a rain-area.

WOLF, F.—Jahrb. drahtl. Telegraph., Berlin, 19, 1922, p. 289.

Gives results of observations at Heidelberg, September, 1919, to August, 1921, on 2,000 and 12,500-metre wave-lengths. In the warm half-year *X*'s developed on the appearance of a new depression over northwest Europe, disappeared on its departure or filling up.

STOYE, K.—Jahrb. drahtl. Telegraph., Berlin, 20, 1922, p. 303.

Observations in the plains of Upper Rhineland, 1915 to 1917, on 600 to 2,000-metre wave-lengths, led to a classification of *X*'s in ten groups.

(1) Prevailing weather-type, a whistling sound decreasing in strength, ending almost in a whisper.

(2) Must type, weak hissing sound.

(3) Cloud break-up type, repeated groups in the form of explosive crashes. Specially marked on break-up of alto-cumulus.

(4) Cirrus type, "trrrrtasss" (palatal *r*), increasing as cirrus gathers, continuing till cirrus ceases to increase.

(5) Lightning type "rrrrrrssss" (palatal *r*), a more rapid *r* succession than in (4).

(6) Front type (squally wind), creak like a revolving clapper.

(7) Cumulus-development type, short single sharp cracks.

(8) Thunderstorm-cumulus type, sharp cracks of different strength, coming in groups.

(9) Sunrise type, violent rattling and scratching of longer duration, not in group form.

(10) Sunset type, superposition of (3), (9), and other types, partly due to surface cooling and condensation, partly to cloud break-up.

Every stage in the development of a thunderstorm released a definite type of disturbance. Groups 4 and 9 are superposed in thunderstorms.

The lightning-type was observed at night with perfectly clear sky.

The increase in disturbance-numbers started several hours before the onset of the thunderstorm, though there were exceptions to this rule.

In spite of unmistakable signs of thunderstorm the number of disturbances remain normal until a sudden release occurred.

Strong disturbances were found to come from strata of misty haze and also from forests with their well-known summer cloud-formation.

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Direction-finding differentiated between sharply directed *X* and those showing little directivity. Localized thunderstorms and squalls could be located in azimuth.

WATSON WATT, R. A.—London, Wireless World and Radio Rev., 12, 1923, p. 601.

Summarises work on *X*'s under the Meteorological Office and the Radio Research Board, gives examples of the location of thunderstorms up to 2,400 kilometers distant, by direction-finding on *X*'s, and discusses the relations of *X*'s, rainfall, and lightning.

BUREAU, R., and others.—C.-R. Acad. Sci., 178, 1924, pp. 556, 1623; 179, 1924, p. 394; 180, 1925, pp. 529, 1122; Onde, Elec., 4, 1925, pp. 31, 58.

Atmospherics are the phenomenon that best gives evidence of the passing of meteorological disturbances in tropical regions; the other meteorological variables only indicate that passing in a much less regular way; moreover, they only give evidence of the meteorological disturbance when it has reached the observing station, while atmospherics announce it some hours in advance.

LUGEON, J.—Paris, C.-R. Acad. Sci., 180, 1925, p. 594.

Observations at Lausanne, 1919 to 1922; at Zurich, 1924.

Preliminary conclusions are stated thus:

"(1) Intensity, frequency, nature, and direction of *X*'s vary with altitude.

"(2) This variation is closely connected with variations of vertical temperature-gradient. . Cooling augments, heating diminishes the phenomenon.

"(3) Lower layers are much more disturbed than higher.

"(4) Apart from *X*'s of proved distant origin, range of *X*'s originating in the lower layers does not seem to exceed 250 km., and remains almost always under 150 km. in mountainous regions."

WATSON WATT, R. A.—London, Proc. Phys. Soc., 37, 1925, p. 23D; London, J. R. Aero. Soc., 29, 1925, p. 170.

Shows correlation between apparent sources of atmospherics and their meteorological environment. Of 490 cases examined, twenty-five per cent fell within 250 km. of reported thunder, a further twenty-eight per cent were associated with more distant thunderstorms or with squall phenomena, twenty-one per cent more with rain, thirteen per cent uncorrelated.

Reports the tracking of a cold front for 2,700 km. by automatic recorders of *X*'s.

Most of them seem to have correlated static with a local condition. I am trying to show how those local conditions are carried along with the general drift of the atmosphere and how static from them can be used in weather-forecasting.

I have listed the above facts in this particular manner in order to show how much can be forecast concerning static once its relationship to High and Low structure is well established. From our knowledge of the development and motion of translation of Highs and Lows we have the basis of a static forecast which will be enhanced by an instrument which will make use of the directional properties of static.

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TRACKING THE MIAMI HURRICANE

Figure 4 shows the Miami Hurricane as it was passing over the Florida Peninsula. Here it will be seen that from Guantanamo where the U. S. S. *Kittery* was then moored the heaviest static was in the general direction of the southeast quadrant. The center of the storm was six hundred miles distant.

Figure 5 shows the location of the centers of the Miami Hurricane from the time it was first observed to the eastward of the Lesser Antilles to the time it filled up and dissipated over Mobile, Alabama. Did not this static belt drift along with the hurricane? How far will a direction-finder be able

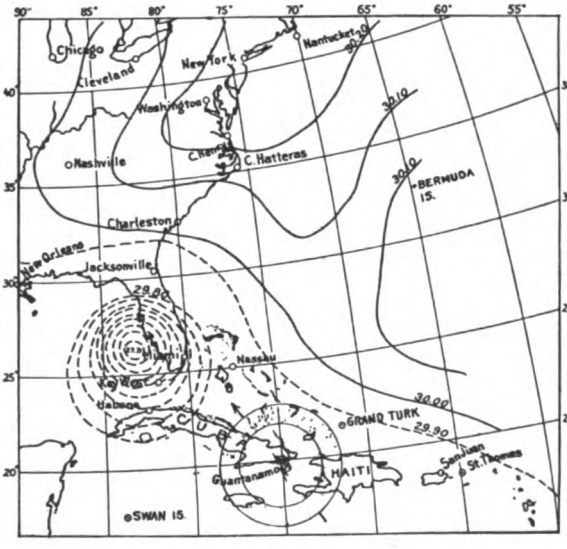

FIG. 4

Miami Hurricane passing over the Florida Peninsula.

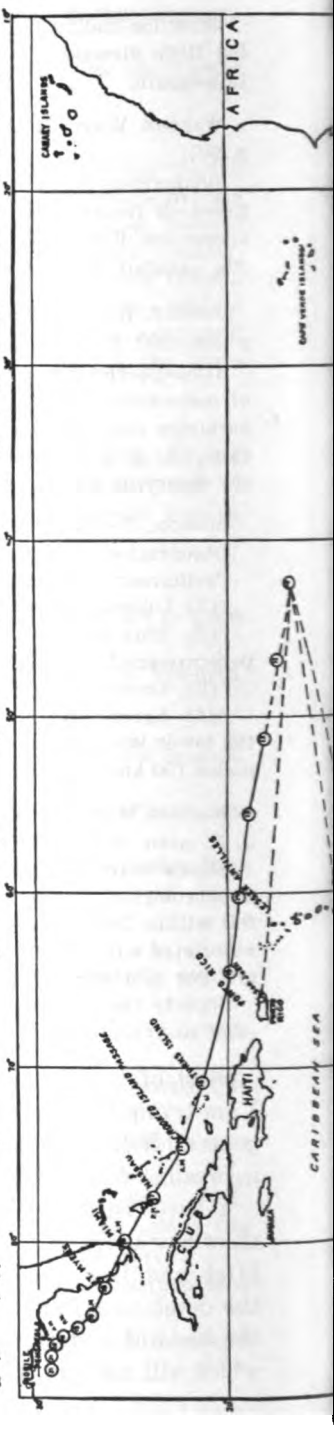

FIG. 5—*Right*

Diagrammatic history of Miami Hurricane including illustration of proposed use of radiocompass in locating and tracing such storms.

(Known path of Miami Hurricane extended through doldrums to easternmost breeding-place of hurricanes with known part of path shown by solid line.)

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to reach out with sufficient precision to make its use practical in habitually tracking such storms. The dotted lines show where the system may enable us to reach out in the region to the eastward of the Lesser Antilles, where barometer-readings are scarce, and to triangulate such a static center in hurricane season from St. Thomas, Barbados, and Trinidad.

THE DOLDRUMS, BREEDING-PLACE OF HURRICANES

Figure 6 shows the ideal atmospheric distribution for summer from which the hurricane-belt, the doldrums, may be studied. In addition to those hurricanes that form to the eastward of the Lesser Antilles, we see the breeding-place for the early spring and late fall type that form around the Isthmus of Panama between the North Atlantic or States High and the South Pacific High. The selection of compass-stations here as elsewhere will depend upon the proved range of accuracy of the radio compass for this kind of work.

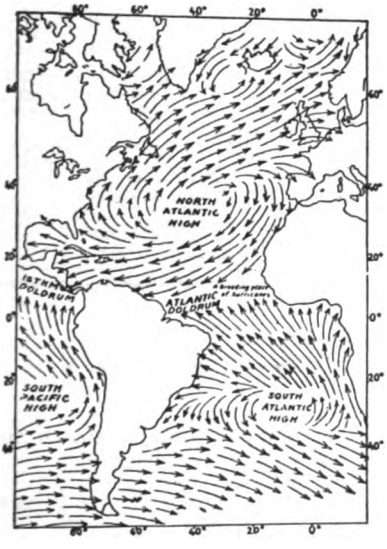

Fig. 6

Breeding-places of hurricanes—doldrums.
(After Bartholomew's "Physical Atlas," volume 3, plate 14.)

Anyone working a field as new and undeveloped as this naturally finds comfort in another independent source wherein his conclusions have been verified. Mr. Friis of the Bell Telephone Research Laboratory has taken observations with an instrument developed at that laboratory over a period extending from last August up to the present date. The laboratory very generously cooperated with the Hydrographic Office in this work and I show you here the results of a part of their observations which substantiate work previously done by me.

Figure 7 shows the High central at Cliffwood, New Jersey, November 25, 1926. Static was zero during the passage of this homogeneous High.

Following its passage, the Low shown in Figure 8 in its motion of translation to the eastward passed over the same station. Static rose in intensity from one to over four hundred microvolts per meter during

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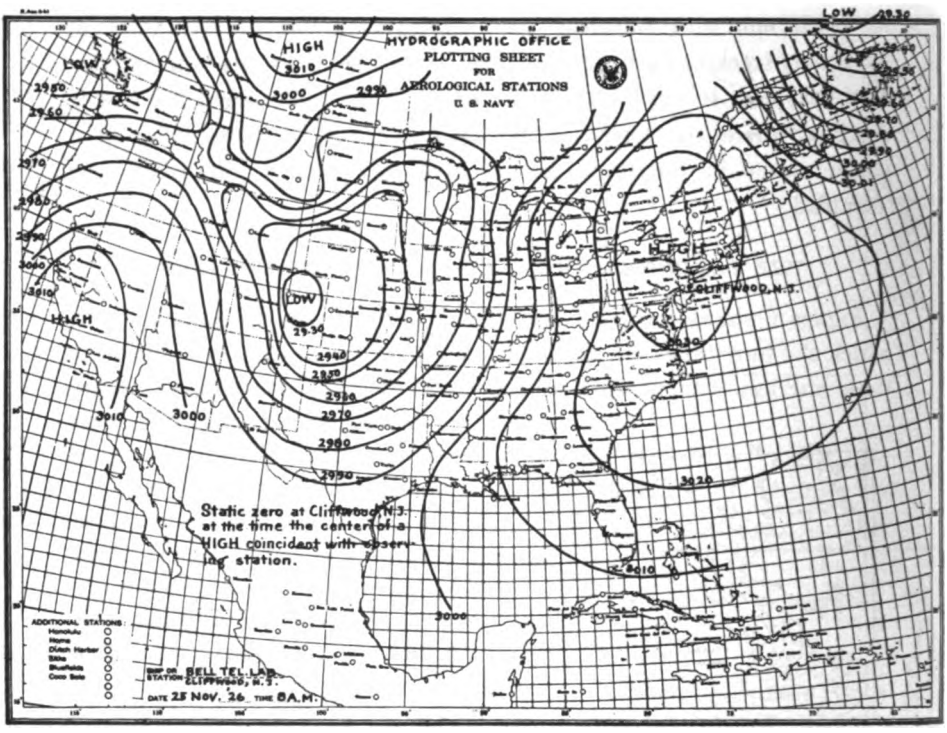

FIG. 7

Communication-conditions and isobars, November 25, 1926, at 8 A. M.

its passage. The direction shifted consistently from west as shown to north of east during the passage.

The graph of direction and intensity of static shown in Figure 9 was received by their machine.

Some idea of the effect of this static intensity on the received signal is gained when the reader realizes that the Bell Telephone System try to maintain for trans-Atlantic work a received signal-strength for code of five microvolts per meter and for telephony of fifteen to twenty microvolts per meter.

The Hydrographic Office is pleased to see its desire of a year ago so quickly fulfilled by commercial enterprise. We said then that an instrument that would record both direction and intensity of static would be necessary to the successful accomplishment of this work. Dr. Austin at the Bureau of Standards has also developed a fine automatic static recorder and there are still others.

The recorder we used is shown in Figures 10 and 11. It is slightly

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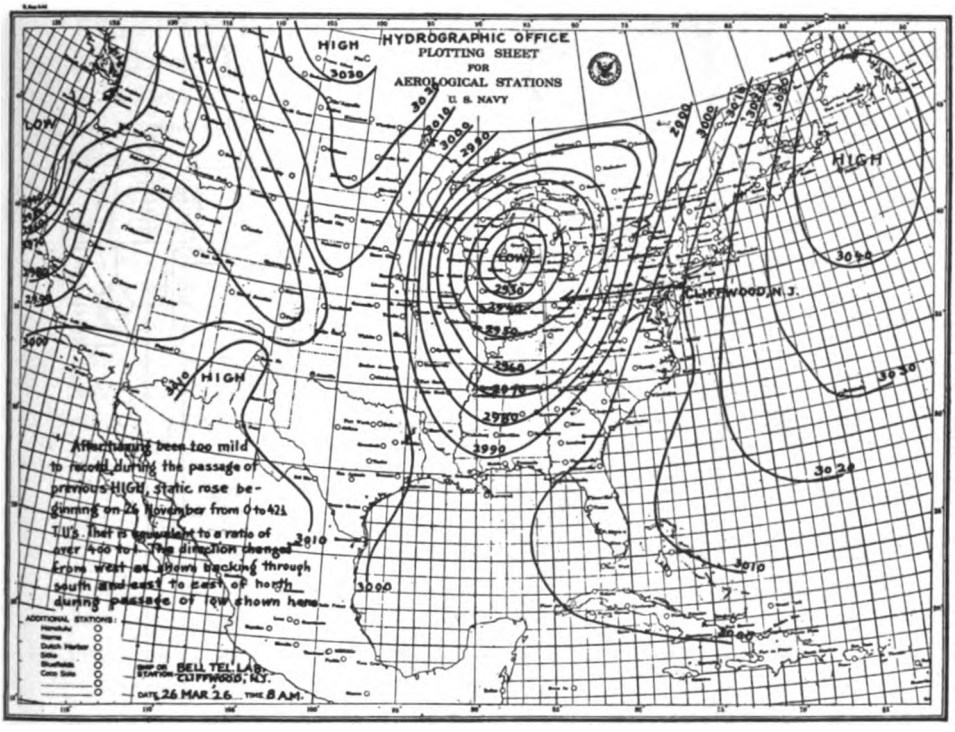

FIG. 8

Communication-conditions and isobars, March 26, 1926, at 8 A. M.

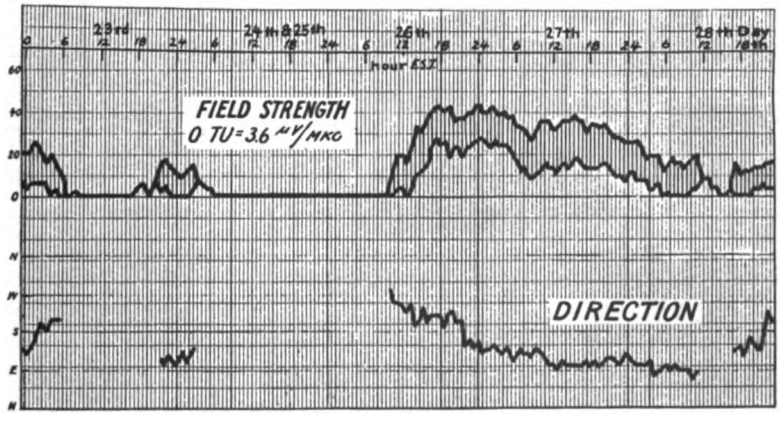

FIG. 9

Intensity and direction of static, November 23 to 28, 1926, as recorded at Bell Telephone Research Laboratory at Cliffwood, New Jersey.

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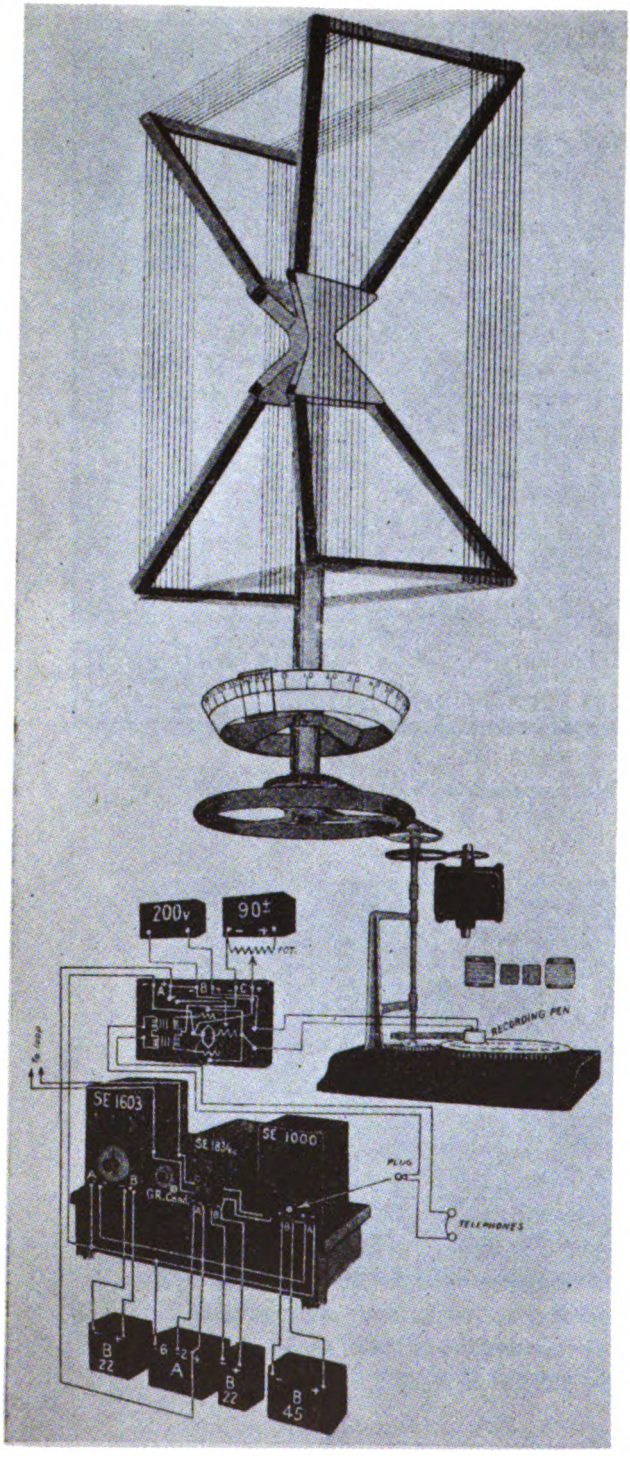

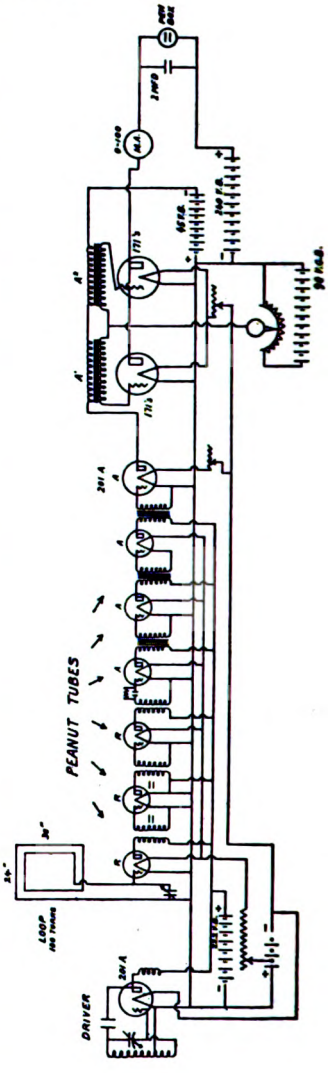

FIG. 10—*Left*

Kincaid static-recorder.

FIG. 11—*Above*

Schematic diagram of Kincaid static-recorder.
(U. S. S. *Kittery* installation.)

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different from the hook-up we used at Bellevue Laboratories which was as follows:

The loop, an *SE*-515*A*, was six feet high, four feet three inches wide, and consisted of ninety turns, spaced over an axial length of four feet three inches. The loop center was grounded.

The terminals were connected to an (*SE*-1934) amplifier and tuned by a 0.01 m. f. d. variable condenser (*SE*-1830).

The amplifier had three radio frequency-stages, a detector, and two audio frequency-stages of amplification.

An additional audio frequency-stage was used, the output of the latter being connected in parallel and the negative grid-bias being adjusted for zero plate-current, at zero signal, by means of a potentiometer. The plate-current of the two tubes actuated a pen which was shunted by a one m. f. d. condenser.

The instrumental combination described above results in depression of the pen for each static crash.

The pen records on a card, which rotates very slowly in synchronism with the compass-loop, two maxima and two minima being indicated for 360° of rotation (a bilateral loop-operation). Some unilateral experiments were conducted at Bellevue.

The motor was so geared as to be able to make one revolution in six to ten minutes. From this it can be seen that each of the inclosed static graphs contains from three to ten complete revolutions of the compass and consumes from twenty minutes to one and one-half hours.

The recorder used at Cliffwood by the Bell Telephone Laboratories is shown in the schematic diagram, Figure 12. It is an ordinary double detection-set that requires altogether ten tubes, of which the last low-frequency amplifier-tube must be able to handle ten watts in order to prevent overloading. The power-supply may be rectified alternating-current.

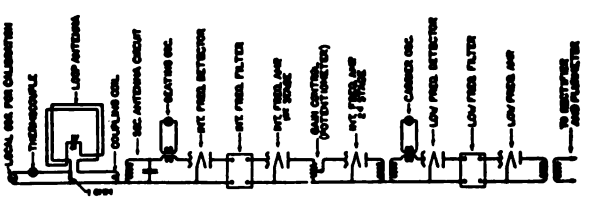

FIG. 12

Schematic circuit-diagram of receiving set.

The gain control is inserted in the first intermediate frequency-amplifier in order to be sure that no tubes are overloaded. The local oscillator shown is used for amplification-calibration of the set and requires no special shielding as its input voltage induced into the loop is comparatively large.

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The selectivity of the set is determined by three separate units, viz., the antenna-circuits, the intermediate-frequency filter and the low-frequency filter, each of which has a specific use. Carson and Zobel [1] have made the following statement.

"In filters designed to select a band of frequencies of width W, the ratio of energy transmitted through the network by the signal and by random interference is inversely proportional to the band-width and increases inappreciably when the number of sections is increased beyond two."

The main purpose of the filters is therefore not to define the frequency-band of the set in so far as static is concerned, but to exclude continuous wave-interference. It is hoped that five hundred cycles wide frequency-bands [2] can be maintained free of c. w. interference for static measurements, and the simplest way to obtain such a band in the receiver is to make the low-frequency filter an efficient low-pass filter that cuts off every frequency above six hundred cycles. More than two coupled circuits are hardly required in the antenna-circuits, but the intermediate-frequency filter ought to have sharper cut-off points than two coupled circuits will give. The selection of filters naturally depends upon the c. w. interference and it may in some cases be possible to reduce the number of filters and thereby make the recorder cheaper. The records shown later correspond to a frequency band of 2,000 cycles—between 57.5 and 59.5 k. c.—but it will probably not be long before c. w. interference makes it necessary to reduce this band-width. It is desirable to have a loud speaker connected to the output of the set and occasionally listen for c. w. interference.

The constant output control-apparatus is shown in Figure 13. The fluxmeter is seen in the upper right corner. Full deflection corresponds to 2×10^{-4} coulomb. The needle is normally free to move except when the cam Z presses the needle down until its point touches the scale OS. The shaft carrying the cam Z and the disc N is rotated one complete turn in fifteen seconds by a clock-motor. The different elements are explained in the figure and the whole action may be understood by studying this carefully. However, it is probably worth while to go through a complete fifteen-second period and explain in detail the purpose of each part.

Time in seconds, 0 to 10:

[1] JOHN R. CARSON AND OTTO J. ZOBEL, "Transient Oscillators in Electric Wave-Filters," Bell System Technical Journal, 2: (3) 27.

[2] Bands at 15, 30, 60, 120 kilocycles would probably be satisfactory.

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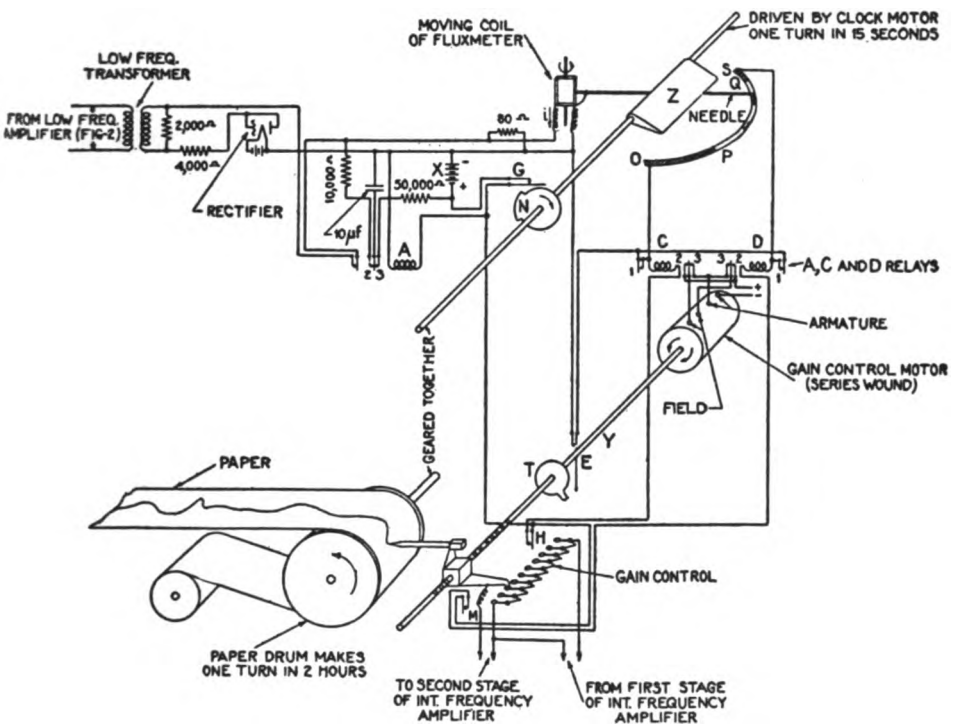

Fig. 13

Schematic circuit of constant-output control apparatus.

Switch *G* is open, therefore relay *A* is open and no current can pass through the windings of relay *C* and *D*. (These relays start the gain control-motor, which is therefore shut off.)

Contact 1 of relay *A* is closed and closes the circuit consisting of the secondary winding of the low-frequency output transformer, the rectifier for the static currents and the fluxmeter. The 2,000 and 4,000-ohm resistances in this circuit insure distortionless input voltage to the rectifier. The fluxmeter is damped by an eighty-ohm shunt. The needle, which was initially at zero, will therefore move, its deflection being proportional to $\int i dt$.

Time in seconds, 10 to 14:

Switch *G* is closed by the cam on the revolvng disc *N* and locks relay *A*.

Contact 1 of relay *A* is opened and opens the rectifier fluxmeter-circuit, thereby bringing the fluxmeter-needle to a stop.

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Contact 3 of relay *A* is closed and makes the battery *X* charge the ten-μf condenser through the 50,000-ohm resistance.

Time in seconds, 11 to 14:

The cam *Z* presses the needle-point down on the scale *OS*. Now, one of three things will happen.

(1) Static has decreased since the last period, so that the needle point will make contact with the metal strip *OP* and close the following circuit: Battery *X*, needle of fluxmeter, winding of relay *C*, switch *H*, and switch *G* to battery *X*. Relay *C* is therefore closed and its closed contact 2, together with contact 3 of the open relay *D* will start the gain control-motor. After approximately half a turn of the gain-control or motor shaft *Y* the needle point is lifted from *OP* by the rotation of the cam *Z*, but relay *C* stays closed due to the fact that it is self-locking through its contact 1, so that the shaft *Y* continues turning until the switch *E* is opened by the disc *T*. This opens the self-locking circuit of relay *C*. Relay *C* therefore opens and the gain control-motor stops after the shaft *Y* has made exactly one complete turn and increased the gain of the set one step (4 transmission units or 1.58 times). Notice that the opening of the needle-point contact does not break any current, due to the use of self-locking relays. This preserves the needle-point contact.

(2) Static has not changed since the last period. The needle point will now touch the insulating strip *PQ* and nothing else will happen, i. e., the gain of the set remains unchanged.

(3) Static has increased since the last period so that the needle-point now will make contact with the metal strip *QS* and close relay *D* and as in case 1 the motor will start and turn the shaft *Y* one turn, but this time in the opposite direction, i. e., the gain of the set is decreased one step.

Time in seconds, 14:

Switch *G* is opened again by the revolving disc *N* and opens relay *A*. Contact 2 of relay *A* is closed and will discharge the 10-μf condenser through the fluxmeter, thereby bringing the needle back to zero. (Notice that the time-constant of this discharge-circuit is $10{,}000 \times 10 \times 10^{-6} = 1.10$ second.)

Time in seconds, 15:

A new period has started.

The purpose of the switches *M* and *H* is to stop the motor when the gain control-switch arm has reached the end of the scale.

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The recorder is of such recent development that no comprehensive data are yet available.

Figure 14 shows part of an actual record of the static received on a set tuned to 57.5 to 59.5 kilocycles. The ordinates represent the attenuation of the gain control of the set, and it is to be remembered that the

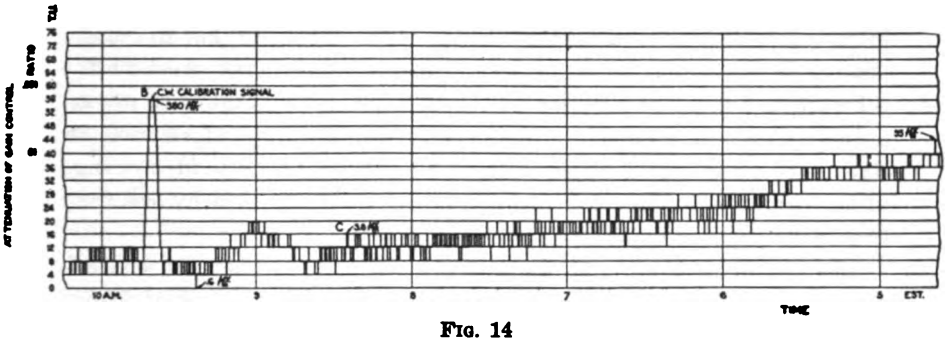

FIG. 14

Static record, morning of October 30, 1925, at Cliffwood, New Jersey.

gain of the rest of the set is constant. The curve shows that the static power on the morning of October 30 changed more than 10,000 times. The point *B* on the curve gives the effect of inducing a local signal of strength 380 microvolts—m in the loop.[3] The point *C* on the curve shows that at 8:25 A. M. the static intensity received on a 2,000-cycle wide frequency-band corresponded to the energy received from a c. w. signal of strength 3.8 microvolts—m. It would be practical always to relate static to such a c. w. signal. Experiments are now being conducted to determine whether the energy received from static is proportional to the width of the frequency-band of the receiving set and if such is found to be the case then it is proposed to have the data relate to a 1,000-cycle wide band. That static is, say, seven microvolts per meter per kilocycle (seven microvolts—mkc) would then mean that the energy of the static received on a 1,000-cycle wide frequency-band is the same as the energy received from a c. w. signal of strength seven microvolts—m.

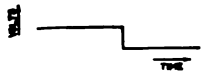

FIG. 15

Shape of impulse voltage.

Attempts have been made to calibrate the set by inducing in the loop, voltages of the shape shown in Figure 15. Relating static to such signals would have the advantage of being independent of the band width

[3] It may be worth while to have such a calibration-signal introduced automatically, for instance once every two hours.

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of the set. Such signals were obtained by closing and opening a mercury-switch, but one signal per second, or ten impulses per period, would overload the set (the tubes) very much. At least ten impulses per second would be required if the set should not be overloaded by each individual impulse, but this would be a difficult task to accomplish and it is therefore recommended that static be measured as explained above, by inducing a local c. w. signal into the loop. The fact that five static crashes in the course of ten seconds—one period—do not overload the set while one hundred impulses of the shape shown in Figure 15 are required to prevent overloading gives us some interesting information on static. It shows that a single static crash is not a single sudden change of the field in the ether and that it can not be represented by less than twenty consecutive impulses.

The record of Figure 14 shows that each step on the gain control-potentiometer is four *TU* and the selection of such steps and of fifteen seconds will now be discussed. To decrease the four *TU* step to a one *TU* step would decrease the speed of the set, i. e., it would take four times longer for the recorder to register a sudden change in the static level which is particularly a disadvantage when the recorder is connected to a rotating directional antenna. On the other hand a step larger than four *TU* would not give the static level with sufficient accuracy. If the time-periods are changed from fifteen to ten seconds, then the "speed" of the set is increased, but the set is then inoperative over a large part of the period since it takes five seconds to change the gain of the set and bring the fluxmeter-needle back to zero. Besides, such a decrease in time-period would increase the probability of overloading and also it would make the energy received per period vary more irregularly especially if static consisted of separate crashes.

Table of conversion of transmission units to ratios

T. U.	Ratio
0	1
6	2
12	4
20	10
40	100
60	1,000

Dr. Friis in describing his static recorder says, "The reason for the small advance which has been made to date in the automatic recording of static is probably due largely to the lack of suitable apparatus. Certainly there has never been any doubt that automatic records would be very valuable. It is just as important to know the static level as it is

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to know the strength of a radio signal because it is the static to signal ratio that determines the intelligibility of the signal. A static recorder connected to a rotating directional antenna-system would tell us where static comes from and, therefore, enable the radio engineer to determine whether it is worth while to construct a directive antenna-system. Also the connection between thunderstorm-areas and static would make static recording valuable to the meteorological service. There is perhaps no reason why a suitable static recorder should not make it possible in a few years to obtain a daily static forecast just as we get our weather forecast now."

I believe another year will see possible such static forecast as Dr. Friis mentions, and with such forecasts will come a more exact knowledge of the relation of storms to static. The result of this will be the identification and tracking of many storms which are difficult especially over ocean-areas where barometer-readings are scarce, and the definite forecasting of communication-conditions.

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POSSIBLE RELATIONS BETWEEN EARTH-CURRENTS, EARTH-RESISTIVITY, AND SOME RADIO PHENOMENA

O. H. GISH

Balfour Stewart in 1882 first suggested that electric currents may exist in the higher regions of the atmosphere and that these currents alter the magnetic field at the Earth's surface and by their changes induce currents in the Earth's crust. This view has later been developed by Schuster and Chapman [1] in turn. In the theory as it stands at present, it is assumed that the primary currents are generated by motion of a highly conductive portion of the upper atmosphere relative to the Earth's permanent magnetic field. This view has received support by the strong evidence, revealed by some radio phenomena, of the existence of a highly conductive region.

Variations in the structure, position, and constitution of this region, which doubtless arise chiefly from changes in solar activity and from the relative positions of Earth and Sun, may be expected to manifest themselves through changes in the phenomena of earth-currents, terrestrial magnetism, and radio.

Since variations in earth-currents are known to be closely related with

[1] S. CHAPMAN, in Dictionary of Applied Physics (2: 551-561) gives a general description of this theory and refers to the principal original papers.

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those in terrestrial magnetism, we may expect to find about the same correlations between earth-currents and radio reception as was found by Pickard [2] between terrestrial magnetism and radio reception. However, data suitable for a statistical study of this relation are not now available. This paper must accordingly be confined to making some comparisons of a rather general nature which it is believed show the desirability of initiating earth-current observations suitable for a comparative study of these two sets of phenomena.

During the year 1926, earth-current disturbances were of more than usual abundance both at the Ebro Observatory in Spain and at the Watheroo Observatory in Western Australia. The year was also exceptionally unfavorable for broadcast reception. The periods when the earth-current disturbances were so great as to interfere with the telegraph traffic were also reported as periods of most unsatisfactory reception.

Earth-current disturbances may be classed as either local or world-wide in character. The latter type occurs, as do many magnetic storms, nearly simultaneously at points as widely separated as the Ebro Observatory in eastern Spain and the Watheroo Observatory in Western Australia. Apparently some disturbances in radio transmission have the latter characteristic, as is indicated by the report that "a bad night for one is a bad night for all." [3]

A 27-day period of recurrence of disturbances in earth-currents, similar to that for magnetic disturbances, has been found by Peters and Ennis [4] in the data from the Ebro Observatory. Hence this may be another feature held in common with radio.

These storm conditions are believed to arise from electric pulses in the upper atmosphere, produced by corpuscular radiation from the Sun. Whether the effects manifested in radio are due to direct action of the magnetic field produced by the pulses, to a change in structure of the conducting region especially at its lower boundary, or to a change in the density and distribution of ions in regions nearer the Earth, are questions which have important bearings in terrestrial electricity, and the answer to these will probably be found in a study of parallel observations of terrestrial magnetism, atmospheric electricity, earth-currents, and radio phenomena.

The normal diurnal-changes in earth-currents have a greater range

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[2] G. W. PICKARD, Proc. Inst. Radio Eng., 12: 119-158 (1924).

[3] See especially BAUMLER, M., Jahrb. d. drahtlosen Teleg., 19: 325 (1922),

[4] Terr. Mag., 31: 57-70 (1926).

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during the daylight hours than at night.[5, 6] The range is also greater in summer than in winter. Thus the variations in normal earth-current activity, daily as well as seasonal, are roughly the reverse of the variations in radio reception of waves of broadcast frequency.

Another point of some interest is that the ratio of the daylight range to the night range in earth-currents is the inverse of the relation found by Taylor between day and night skip-distances. In the means for Watheroo in 1924 the daylight range was three times the night range, at Ebro (1914-1918) 2.5 times, and at Berlin (1884-1887) 3.9 times. Taylor and Hulburt [7] state that "the night skip-distances are on a rough average three or four times the corresponding day values." Since the effective height to the conducting region is proportional to the skip-distance, this may perhaps be taken to indicate that the amplitude in the normal earth-current variation depends rather directly upon the distance between conducting region and Earth.

The sunrise and sunset effects on radio reception which have been reported seem to have no counterpart in earth-currents.

Some features similar to atmospherics are observed in earth-currents. Although earth-current disturbances always accompany magnetic storms, occasionally pronounced earth-current disturbances occur at magnetically quiet times. Some of these can be associated with nearby thunderstorms, but others of equal magnitude occur when no thunderstorms are in view. These disturbances are all of periods of the order of a minute or more. There are, however, also earth-current variations of audio frequency.[8, 9, 10] These can be noted at times on telephone systems in which a ground return is used. The noises which these produce in a telephone receiver are notably of the same variety produced by atmospherics. These are reported to predominate in certain directions, according to some observers along the magnetic meridian.

An examination of a number of earth-current storms, where the period of the variations was of the order of ten minutes and occurring at widely different times and places, shows a strong predominance of change along the magnetic meridian. Schindelhauer [11] reports that "some types of

[5] B. WEINSTEIN, Die Erdströme im deutschen Reichstelegraphengebiet und ihr Zusammenhang mit den erdmagnetischen Erscheinungen. Braunschweig, 1900.

[6] L. A. BAUER, Terr. Mag., 27: 1-30 (1922).

[7] Phy. Rev., 27: 189-215 (1926).

[8] J. LANDERER, Compt. rend., 105: 463-465 (1887).

[9] W. H. PREECE, Nature, p. 554, April, 1894.

[10] R. COURANT, Die Naturwissenschaften, 14: 61-64 (1926).

[11] F. SCHINDELHAUER, Jahrb. d. drahtlosen Telegr. u. Telephonie, 22: 163 (1923).

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(atmospheric) disturbances occur day after day along the direction of the magnetic meridian."

It may also be of interest in this connection to know that earth-current records at the Huancayo Magnetic Observatory, 12° south of the equator and at an altitude of 11,000 feet above sea-level, which began in October 1926, show phenomenal earth-current disturbances. During the period October 15, 1926, to January 31, 1927, the frequency of occurrence and magnitude of these far exceed any heretofore reported. The great majority of these corresponds closely with changes in the magnetic elements. Whether these disturbances are related with such atmospherics as apparently came from the tropics would seem a question worthy of investigation.

Doubtless some of these apparent correspondences will, with sufficient data, prove to be mere coincidences. Yet it is believed we have sufficient grounds to urge a closer comparative study of these terrestial phenomena. To this end, more suitable data are needed. This applies especially to earth-currents. At present good progress is being made in methods and instruments for recording the several radio phenomena. The methods and instruments for recording the earth-current features of most interest in this connection are at hand, but these are in use at present at only four places, two in Europe, one in South America, and one in Western Australia.

These earth-current installations are designed for recording variations of periods of a few minutes and upwards, and, although it is hoped that more such systems will soon be installed, especially in North America, yet they are not well suited for the individual investigator. The observation of higher frequency earth-current phenomena is, however, free from some of the obstacles attending the other type of measurement. The earthed points can be placed at much shorter distances apart, and the character of earth-plates is a matter of considerably less moment than for installations where the longer period variations are to be recorded.

Although these high-frequency earth-currents doubtless have their corresponding magnetic effect, the usual magnetic measuring instruments do not respond to them. Furthermore, according to the calculations of Chapman, and this is apparently borne out in the observations, the amplitude of the surface earth-current increases, relative to that in the Earth's magetism, as the frequency increases. It thus happens that earth-current methods are especially adapted for investigating this feature.

The resistivity of the Earth as a whole is a matter of considerable importance in theories of terrestrial magnetism. That of the core of the

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Earth has been calculated by Chapman and Whitehead [12] both from magnetic diurnal-variation and from storm data; that of the oceans may be considered as known; but that of the undisturbed crust is as yet largely a matter of conjecture. A knowledge of this is needed in connection with the usual earth-current potential measurements in order to determine the current-density. The method and instruments developed by the Department of Terrestrial Magnetism and used at Watheroo Observatory, Western Australia, and at Ebro Observatory, Tortosa, Spain, for making resistivity-surveys seem to supply some of the desired information. It is believed that, if such surveys were made in conjunction with the charting of lines of equal signal-intensity about a sending station, the knowledge of earth-resistivity thus obtained would be considerably enhanced in value, not only to the geophysicist but probably also to the radio engineer.

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Washington, D. C.

APPARATUS FOR RECORDING RADIO PHENOMENA [1]

T. PARKINSON

This paper is devoted to a brief description of the types of apparatus suitable for general use for the measurement of radio field-intensity, fading (fluctuation of field-intensity), and intensity and direction of atmospheric disturbances ("static"). Fundamentally the same equipment may serve all three purposes. Fading records provide relative field-intensities; it is therefore only necessary to add to a fading recorder a means of calibration in absolute units to interpret data in terms of field-intensities. In the study of atmospherics, their intensities and the location of the sources of disturbances are of prime interest; therefore the only additional apparatus required is a rotating coil-antenna, used preferably in conjunction with an open antenna as a unidirectional system.

The essentials of recording apparatus are: the receiving system, the indicating device, and the means of translating indicated changes into graphical records. To obtain measurements in absolute values a calibrating unit must also be used.

[12] Trans. Camb. Phil. Soc., 22: (25), 463-482 (1922).

[1] Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

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Receiving system.—In the receiving system we must consider both the antenna and the receiving set proper.

The antenna.—The type of antenna will vary with the purpose of the measurements. For observations of fading, any type of antenna may be used but the characteristics of the fading are likely to vary greatly according to whether we use a directional or a non-directional system. Among the directional types are the coil-antenna and also the inverted L when it is low and relatively long. While we are not certain just how much of fading is due to lateral and vertical direction-shifts in the received wave and how much to absorption and interference phenomena, we shall avoid the directional antenna if we wish to eliminate the effect of horizontal direction shifts from our records, and we shall choose the vertical antenna, the T-type, or an inverted L that is relatively high.

For measurement of field-intensities the coil-type of antenna, with a grounded center tap for securing balance, is most convenient because of its portability and because its constants are easily measured. The latter fact makes it possible to match with a local signal the voltage induced in the coil by the received signal and thus calculate the field. The open type of antenna is also satisfactory but necessitates a more roundabout method of measurement and calculation.

For direction measurements, whether of atmospherics or of lateral shifts in received signals, the coil-antenna of the balanced type may be used but the coil-antenna in conjunction with an open antenna is preferable. With the latter system the minimum signal or nul point, by which direction is most sharply determined, occurs in one direction only. With the coil-antenna used by itself there are found minima for two opposite positions of the coil. In the unilateral arrangement the open antenna and the closed coil-type are inductively coupled so that a composite of the signals received by the two systems is impressed on the receiving set. By means of a resistance in the tuned circuit of the open antenna, the signal is reduced until it is approximately equal to the maximum signal received in the coil-antenna alone when the latter is normal to the wave-front of the received signal. The combined signal from the two systems with the coil in this position will be double that of either alone if the voltage phases of the two are the same, but will be zero if the phases are opposite. As the coil is rotated there will always be a maximum when one side points in the direction of the received signal and a minimum when the coil is reversed. The direction in which the latter side points therefore determines the signal direction. The coil may be rotated at definite speed by any driving mechanism which will not create a field of its own in the coil. For signals at the

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low frequencies and for such signals at higher frequencies as do not involve considerable fading, automatic records can thus be made.

Receiving set proper.—In selecting the receiving set proper we naturally seek dependability first and then simplicity. The former requirement eliminates the crystal detector from any part of the measuring circuit, since no crystal rectifier can be counted upon to remain constant in sensitivity over long periods of time.

The simplest circuit which will give reasonable sensitivity is the autodyne, commonly known as the regenerative detector. Here the tube-circuit is so tuned that a beat-note is produced between the generated and the incoming signal. This beat must always be of the same frequency if results are to be comparable, since no receiving circuit is equally sensitive to all frequencies. For work at broadcast and higher frequencies this arrangement has disadvantages: (1) It is practically impossible to repeat adjustments, particularly so far as to secure the same amount of regeneration; (2) it distorts modulation so as to make monitoring disagreeable; (3) it practically necessitates continuous calibration by some method of matching the antenna-signal directly by a measured signal; (4) the circuit is not sufficiently selective.

Turning to radio-frequency amplifiers of the neutrodyne type we find a gain in dependability but a loss of simplicity. The advantages are: (1) Selectivity is improved by using extra tuned circuits; (2) because regeneration is avoided it is possible to duplicate tuning and amplification; (3) calibration of the amplification of the set for any given frequency is possible. The disadvantages are: (1) There are too many tuning controls; (2) any amplification-control, such as a variable resistance, will have a varying effect for signals of different frequencies, thus necessitating its complete calibration over the whole frequency-range of the receiving set.

The superheterodyne[2] or double-detection circuit-system seems most satisfactory for general use. In addition to the mentioned good points of the neutrodyne and the reduction of tuning controls from three to two, the following advantages are worth noting: (1) Beyond the first detector the frequency is always the same and therefore the amplification is uniform regardless of the frequency of the received signal; (2) for any given frequency the amplification of the signal before reaching the intermediate-frequency amplifier remains the same so that a calibration showing relative sensitivities of this portion of the circuit-system to the

[2] A satisfactory superheterodyne of standard make can be purchased for $300 or less.

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different frequencies can be used to correct any measurements made at the output of the receiver; (3) the fixed intermediate- or beat-frequency, of say forty kilocycles, which for practical purposes is now the carrier, can easily be isolated from modulation-effects by means of a transformer tuned to this frequency and coupled to a rectifier and indicating device; (4) one calibration of the amplification-control serves for all input frequencies, since this control affects only the amplifier and following stages, where the same beat-frequency is always involved; (5) a calibrating unit is required only from time to time for verifying and checking purposes and therefore one such unit can serve for several receiving sets, and the size of the measuring outfit can be reduced for field use.

Figure 1 shows the slight modification of the superheterodyne which

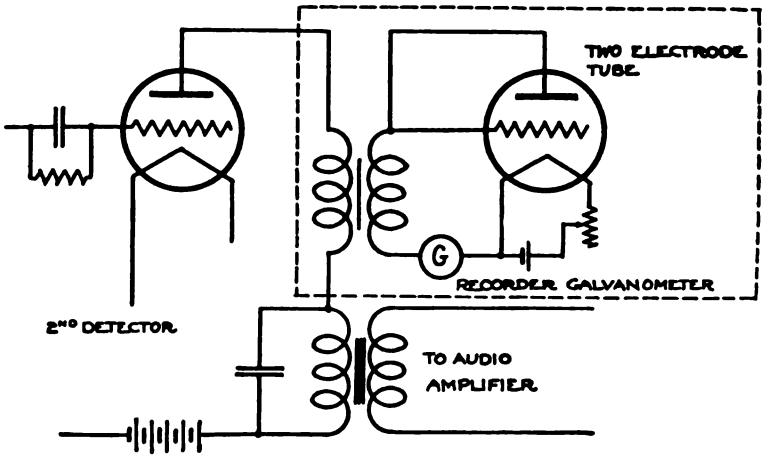

FIG. 1

Circuit connections of recorder unit to superheterodyne receiving set. (Circuits of recorder unit are enclosed within broken-line rectangle.)

must be made to adapt it to recording purposes. The two-electrode tube-rectifier, the intermediate-frequency transformer, and the recording galvanometer shown within the broken-line rectangle constitute the additional apparatus required. This may be placed in the receiver-cabinet or may be in a separate unit outside. The wiring of the set is modified only by opening up the plate-circuit of the second detector, or of the last intermediate-frequency amplifier, to insert leads to the primary of the extra transformer. In place of the two-electrode tube-rectifier indicated it is possible to employ the three-electrode type with plate-current balanced out of the indicating device. The additional apparatus involved by the latter arrangement consists of a *B* battery, a balancing battery

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and resistances. In either arrangement voltmeters or else ammeters are essential in both *A* and *B* battery-circuits to indicate whether conditions are being kept constant. In some superheterodynes it is also advisable to change the method of volume-control. Adjustment of the filament-current from a tube by means of separate rheostat does not offer a stable calibration. A very satisfactory arrangement is a variable resistance or potential-divider shunted across the primary of the first intermediate-frequency transformer. This control should be calibrated in steps which have a known ratio to the maximum amplification of the set.

Calibrating unit.—One type of calibrating unit consists of a well shielded oscillator capable of producing a current of the same frequency as the incoming signal in the receiving set. This current is introduced through a small resistance inserted in the receiving antenna, and by means of an attenuation network can be made to produce a voltage in the antenna which will match the voltage produced there by the signal to be measured. From the input current, the number of turns and the dimensions of the coil-antenna it is then possible to calculate the field-intensity. Another arrangement which requires less careful shielding is described by Van Roberts.[8] This system does away with the attenuation network and permits the measurement of the calibrating current by means of a sensitive direct-current meter.

Indicating devices.—Indicating devices may utilize sound-intensity or visual indicators of the galvanometer or the potentiometer-type. The first requires matching of pitches and intensities with those of some known values, as in Austin's comparator-method. This method is especially applicable to measurements at the low frequencies where C. W. or I. C. W. signals are interrupted by keying, sufficiently to cause variable errors in galvanometer-records. A 1000-cycle tuning fork produces the constant pitch; the autodyne receiver is adjusted to translate the incoming signal to a beat-frequency of one thousand cycles, and then the comparator-current is adjusted by means of a potentiometer until the two signals are of equal intensity in the telephone-receivers. Knowing the current in the telephones, the amplification of the receiving circuit and the antenna-constants it then becomes possible to calculate field-intensities. For measurement of the modulated and of the rapidly fading signals at broadcast and higher frequencies this method is practically impossible.

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[8] WALTER VAN B. ROBERTS. A method of generating and measuring very weak radio-frequency currents. J. Franklin Institute, 301-310, March (1926).

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Of the visual indicators, the direct-current galvanometer utilizes the rectified carrier-current and gives deflections approximately proportional to the squares of the field-intensities. Its advantages are: (1) It makes continuous records possible; (2) it integrates the audio-frequency changes, thus isolating the carrier from modulation-effects, which is absolutely necessary for measurements of broadcast transmissions. The disadvantages are: (1) Extra analysis is required to translate the ordinates of a record from square-law to straight-line relationships; (2) the square-law effect reduces seriously the galvanometer-range for field-changes, thus necessitating frequent readjustment of receiving-set amplification to keep the galvanometer-pointer on the scale, and adding complications to the analysis work.

The potentiometer-method operates on what is sometimes called the slide-back principle (Figure 2). With a given signal a deflection is pro-

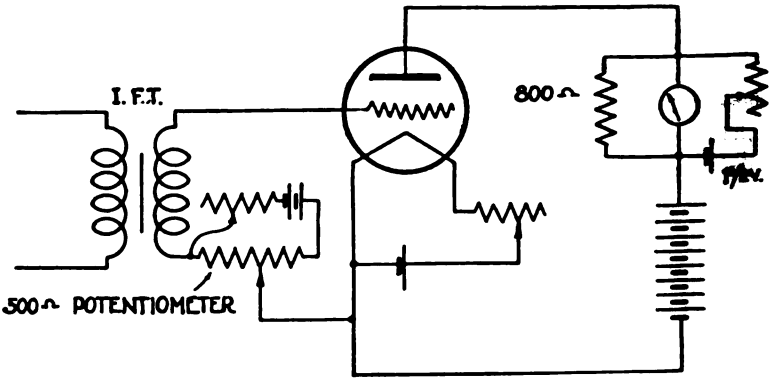

FIG. 2

Circuit diagram for potentiometer-type of recorder.

duced in the galvanometer. By means of an opposing current through the galvanometer the deflection is reduced to an arbitrary zero at the center of the scale. As the deflection indicates that the signal has increased, the potentiometer is readjusted so as to neutralize the increased positive charge on the detector-grid by an equal negative potential, thus bringing the galvanometer-deflection back to the central position. As the signal fades the negative potential on the grid is similarly reduced by the opposite potentiometer-adjustment and again the pointer returns to zero-position. The advantages of this method are: (1) It makes it possible to record with ordinates directly proportional to antenna-currents; (2) it can be made to control the whole amplification-system beyond the first detector, thus preventing possible saturation of amplifier-

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tubes. With this latter arrangement, however, there is an inverse relationship between deflections and antenna-currents. The disadvantages are: (1) It is difficult to keep the deflection even approximately constant by *manual* control of the potentiometer; (2) the inertia of the recording system in automatic apparatus restricts its usefulness for studying the character of rapid fading.

Translating into graphical records—Indicated variations of signals may be translated into records: (1) By plotting readings taken at regular intervals; (2) by following deflections with a manual control[4] linked to a recording pen which writes on a moving tape, as with the Shaw recorder (Figure 3) for example; or (3) by automatic recorders

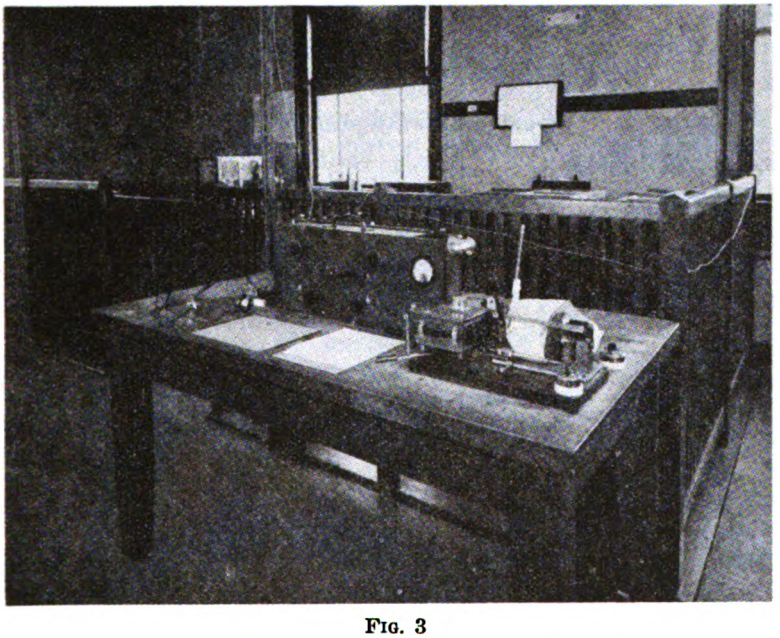

FIG. 3

Receiving set and manual recorder.

of the photographic or mechanical[5] types. Plotting eliminates the details which accompany rapid fluctuations. Manual recording is tedious and expensive in personnel if done for long periods. The mirror galvanometer is expensive and time-consuming because of photographic features. Both mirror and mechanical types of automatic recorders are

[4] Such apparatus can be made up or can be purchased for approximately $100.

[5] A good mechanical recorder can be purchased for approximately $300.

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open to the criticism of square-law complications. The automatic potentiometer[6] is open only to the criticism of slow action preventing the recording of details such as appear at broadcast and higher frequencies. Where much observing is to be done and the variations of a few seconds are not of prime interest this type of apparatus is probably the most satisfactory because it makes possible the securing of excellent records with a minimum of analysis work and of routine observing.

BIBLIOGRAPHY

This bibliography contains references to a few of the articles which should be of most practical value to persons desiring to set up recording apparatus. Systems of various degrees of complexity are presented in this literature. For an extensive set of references on measurement work on radio phenomena, see Bureau of Standards Letter Circular No. 207, "Bibliography on radio wave-phenomena and measurement of radio field-intensities." An article entitled "Die Ausbreitung der elektromagnetischen Wellen," by A. Sacklowski, in the Elektrische Nachrichten Technik, vol. 4, January 1927, gives a good résumé of methods of measuring radio wave-phenomena, and includes an extensive bibliography.

Field-intensity measuring apparatus

A method of measuring radio field-intensities and atmospheric disturbances. L. W. Austin and E. B. Judson. Proc. Inst. Radio Eng., 12: 521-532 (Oct. 1924).

Radio transmission-measurements on long wave-lengths. H. H. Beverage and H. O. Peterson. Proc. Inst. Radio Eng., 11: 661-673 (Dec. 1923).

Portable receiving sets for measuring field-strengths at broadcasting frequencies. A. G. Jensen. Proc. Inst. Radio Eng., 14: 333-334 (June 1926).

A radio field-strength measuring system for frequencies up to 40 megacycles. H. T. Friis and E. Bruce. Proc. Inst. Radio Eng., 14: 507-520 (Aug. 1926).

Separate calibrating units

How was reception last night? Albert F. Murray. Radio Broadcast, 9: 300-304 (Aug. 1926).

A method of generating and measuring very weak radio-frequency currents. Walter van B. Roberts. Journal Franklin Institute, 201: 301-310 (March 1926).

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[6] A standard potentiometer-recorder which can be adapted to the purpose may be purchased for $250 to $300.

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Fading recorders

Short-period variations in radio reception. G. W. Pickard. Proc. Inst. Radio Eng., 12: 119-158 (April 1924).

How was reception last night? Albert F. Murray. Radio Broadcast, 9: 300-304 (Aug. 1926).

Cooperative investigation of radio wave-phenomena. Bureau of Standards report R113-o.

An automatic fading recorder. T. A. Smith and G. Brown. Proc. Inst. Radio Eng., 15: 41-47 (Jan. 1927).

Recorders of atmospheric disturbances

See references under "Directional antenna-systems and applications."

A static recorder. H T. Friis. Bell System Technical Journal, 5: 282-291 (April 1926).

Directional antenna-systems and applications

Determination of the direction of atmospheric disturbances or static in radio telegraphy. L. W. Austin. Journal Franklin Institute, 191: 619 (1921).

Loop uni-directional receiving circuits for the determination of the direction of atmospheric disturbances. L. W. Austin. Proc. Inst. Radio Eng., 11: 395-97 (1923).

Tracking static to its lair. E. M. Terry. Popular Radio, 6: 342-49 (Oct. 1924).

The directional recording of atmospherics. R. A. Watson-Watt. Experimental Wireless (London), 3: 234-238 (April, 1926).

An instantaneous direct-reading radiogoniometer. R. A. Watson-Watt and J. F. Herd. Experimental Wireless (London), 3: 239-241 (April 1926).

Direction and position finding by wireless. R. Keen. The Wireless Press, Ltd., London, 1922.

The radio direction-finder and its application to navigation. F. A. Kolster and F. W. Dunmore. Bureau of Standards Scientific Papers, 17: 539-566 (1922). Can be secured from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 15 cents.

Sur la radiogoniometrie des parasites atmospheriques et la prevision des temps. E. Rothe. L'Onde Electrique, 2: 7-18 (1923).

(The following articles pertain to direction-measurements and also wave-front angles.)

Some measurements on wireless wave-fronts. R. L. Smith-Rose and R. H. Barfield. Experimental Wireless (London), 2: 737-742 (Sept. 1925).

Further measurements on wireless wave-fronts. R. L. Smith-Rose and R. H. Barfield. Experimental Wireless (London), 4: 130-139 (March 1927).

Polarization of radio waves. G. W. Pickard. Proc. Inst. Radio Eng., 14: 205 (April 1926).

Changes in the polarization of radio waves. G. W. Pickard. Radio News, 7: 1540-1541 (May 1926).

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Washington, D. C.

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SUMMARY OF SYMPOSIUM ON CORRELATIONS OF VARIOUS RADIO PHENOMENA WITH SOLAR AND TERRESTRIAL MAGNETIC AND ELECTRIC ACTIVITIES[1]

J. H. DELLINGER

The papers presented on this program cover a wide scope and variety of fields of scientific work. It is significant that the general subjects of the symposium provide a sufficiently common ground so that workers in these diverse fields of scientific effort can understand and appreciate the technical results of work in the other fields. In these various fields of geophysical observation we have all for many years past been both troubled and interested by the same sorts of variations, fluctuations, and anomalies in the phenomena with which we deal. A suspicion that the similarity of character of variations in the various phenomena indicates some common underlying cause furnishes the reason for the organization of this symposium. The symposium has been most successful in the wealth of material brought forward and the clear indication offered of correlations between the several types of phenomena. It is my task to summarize the discussions and to indicate such general conclusions as may be drawn from the whole field of study.

In starting the symposium, Chairman Heck brought to our attention the recently recognized importance and value of the observation of radio wave-phenomena in their bearings upon other terrestrial phenomena.

Appropriately, the first technical paper of the session was presented by Dr. Abbot on the source and basis of the various geophysical variations—the Sun. The Sun is not only the source of the energy by which life and all of our activities are maintained, but it is also the source of the troubles we have in our various fields of scientific endeavor. Dr. Abbot gave us a clear idea of the various solar cycles with their periodicities of various types. Analyzing for certain of these cycles, he has found definite general correlations between his major subjects of study, solar radiation and sunspots. In addition, he gave us an indication of the degree of correlation between these phenomena and such things as weather, radio wave-intensity, and radio atmospheric-disturbances. There are clear general correlations in these various fields, but the specific trends of the various phenomena have either no direct correlations or else are very complicated. It is evident that the phenomena dealt with are of a complex nature and that there is a great need for methods of study and analysis to be worked out which will unscramble some of the

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complexities. Dr. Abbot indicated some points of departure for the unscrambling process. An example of a suggestion of this kind is the discovery that sunspottedness is more significant when relatively small; that there is, so to speak, a saturation-effect when sunspottedness is great and, consequently, correlations with other phenomena are clearer for relatively small values of the sunspot-numbers.

In Dr. Bauer's paper, we were informed of the correlations between sunspottedness and variations of intensity of the Earth's magnetism and electricity. There are correlations in the general course of the two phenomena. Detailed records, however, do not always show a satisfactory direct correlation between sunspots and either magnetic storms or atmospheric electricity for short periods. Dr. Bauer pointed out that the magnetic phenomena and the sunspots may both be due to some undiscovered solar cause.

Dr. Nicholson's paper, presented by Dr. Adams, informed us of a most promising type of investigation of the phenomena in the Sun which are of a more basic nature than the sunspots. By means of the spectrohelioscope which is used in the investigations directed by Dr. Hale, studies are being made of the actual intensities of the Sun's magnetic field in and near the sunspots. Obviously, the sunspots are only one indication of the electric and magnetic actions on the Sun which are the actual causes of the variations which we study, and work of this kind, therefore, penetrates much nearer to basic causes. The work with the spectrohelioscope thus gives a new hope throughout the whole field of geophysical investigations, and doubtless the taking of spectroheliographs in the future will afford a new line of data with which correlations can be expected to be of a much more direct and informing nature.

Mr. Pickard presented a number of entirely remarkable correlations between radio reception and sunspot-numbers. The clear indications of direct relation which he showed do much to unscramble the complexities and vagueness of the inter-relations between the several phenomena in which we are interested. It is very interesting to note that while extraordinary agreement was shown between the shape of the curves showing the variation of sunspots, Earth's magnetism, and radio reception, in the 27-day and other solar cycles, nevertheless in all cases the phases of these curves were different (by a few days). Furthermore, the shift of phase is not the same between the curves of the different phenomena or curves taken at different times or under different conditions. This lack of agreement as to phase of the various phenomena is significant in regard to the validity of sunspots as a criterion of the Sun's activity. For example, Mr. Pickard found that when data were compared with

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sunspot-numbers not for the whole solar disc but only for the central zone of the Sun, much better correlations were found; in other words, the electric and magnetic actions on the Sun unquestionably control the variations of the terrestrial phenomena we observe, and the sunspots are only a first approximation as an index to that solar activity. A truer index remains to be found.

Dr. Austin showed that for observations taken at relatively low radio frequencies there was little direct correlation of atmospheric disturbances and sunspots. There was definite indication of general correlation but this practically disappeared when any detailed study of the phenomena was made at specific individual times. In contrast, Dr. Austin showed the very good correlation between intensity of atmospheric disturbances and temperature. This contrast is significant and probably finds its explanation in the view that the observations of atmospheric disturbances were made at relatively low radio frequencies. The transmission of the waves producing the atmospheric disturbances at a particular point is largely determined by ground transmission-conditions and relatively little by conditions in the upper atmosphere. As the ground-conditions vary with temperature, the temperature-correlation mentioned would be expected; whereas, since the solar emanations have their effect largely in the ionized upper atmosphere, these particular radio observations would not be affected in marked degree by the solar variations.

Dr. Breit drew for us a picture of the constitution of the Earth's atmosphere which is now generally accepted as providing a mechanism for the transmission of radio waves to great distances. This involves the assumption of an effective atmosphere extending some hundreds of miles out from the Earth, the upper portions of which are highly ionized and are often referred to as the Heaviside layer. Utilizing probable values for the ionization of the upper atmospheric regions, Dr. Breit calculated the variations of radio wave-intensity received at great distances for small variations in values of the Earth's magnetic field. He concluded that as small a variation as five gammas in the Earth's field can make appreciable changes in received radio-intensity at reasonable distances. This work gives a basis for direct estimation of the rôle of terrestrial magnetic variations in the variations of radio reception. This also led to the suggestion of the value of future simultaneous measurement of received radio field-intensities and terrestrial magnetic variations.

Lieutenant Kincaid described some correlations between meteorological phenomena and radio atmospheric-disturbances which have an immediate practical application in marine navigation. By observations of the direction of the source of atmospheric disturbances and either observing the

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course of that direction with time or by triangulation, important correlations were worked out between the sources of these disturbances and atmospheric highs and lows. This is leading to a practical means of tracking violent storms at sea and giving a valuable direct aid both to weather forecasts and to radio forecasts. In this work valuable use is made of apparatus for the automatic recording of the intensity and direction of atmospheric disturbances.

Mr. Gish pointed out that earth-currents offer an additional type of phenomena whose variations may be of importance in determining the correlations between solar activity and terrestrial phenomena. Since there are in the world only three observatories for regular measurements of earth-currents, and these are relatively new, there does not exist a large body of data which can now be studied and the existence of correlations cannot therefore be determined at this time. A number of facts, however, indicate that results of value may be expected. It is well known that earth-current disturbances are sometimes so pronounced as to put wire telegraphs out of service. There are reasons to believe that some earth-current variations follow the same course as radio atmospheric-disturbances and radio reception-conditions. In any event this is a line of work which offers possibilities and should be kept in mind in further study of this general field.

Mr. Parkinson brought to our attention that radio observations are now of considerable importance in geophysical studies, not only because of demonstrated correlations, but also because in recent years facilities for precise and pertinent radio measurements have been highly perfected. Radio measurements have greatly advanced in recent times and accurate and useful observations can be made with relatively simple apparatus. So valuable and at the same time so easily made are radio observations that it is to be expected that observatories of many different types of organizations which have not hitherto included radio-recording will undertake observations in this field. With very simple apparatus and measurement-procedures, it is quite possible to provide for records of fading (signal-intensity fluctuations), radio field-intensity, and both the intensity and direction of atmospheric disturbances. Laboratories which care to make more detailed studies of radio phenomena can readily add observations for determination of radio wave-direction and polarization. Mr. Parkinson gave definite information as to the several components of the necessary apparatus, including antenna, receiving set, recording unit, and (where desired) automatic graphic record-maker. Observatories which are not in a position to assume any great additional expense can provide equipment for the principal radio observations at a cost of

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a few hundred dollars. This will be reduced in many cases as the receiving set, which is the principal part of this expenditure, would already be available at some institutions. Where the observatory desires to undertake radio measurements on a considerable scale and provide for automatic recording so as to minimize the expenditure of time on the part of personnel, the necessary equipment can be provided at a cost of a few thousands of dollars.

CONCLUSIONS

The contributions to this symposium made by the several speakers justify the following conclusions:

(1) The present time is one of emergence of a considerable amount of new knowledge on solar activity and its effects on geophysical phenomena. The numerous types of variation exhibited in these various phenomena which have been the constant object of study and oftentimes the despair of students in these several fields, are just now coming to evince a common nature and origin. The mechanism which, at least in large part, determines and explains the several types of variation is the emission of electric and magnetic radiations by the Sun and the production of effects thereby in the Earth's atmosphere. The major portions of these effects occur in the upper ionized portions of the air frequently referred to as the Heaviside layer, a region extending from approximately one hundred to four hundred miles out from the Earth's surface.

(2) Vast opportunities for the co-ordination of world-wide observations and the correlation of universe-wide phenomena is opening up. Many observatories which have been established by organizations set up to deal with one type of phenomena only (e. g., meteorological or magnetic phenomena) can most profitably and certainly reach their goal if they no longer limit their observations to the one line in which they are directly interested. The new possibility and desirability of co-ordinating research along the various geophysical lines must in the future affect the location of observatories with a view to the establishment of a co-ordinated program of study of terrestrial phenomena on a world-wide scale.

(3) Although we are far from the position where positive conclusions can be drawn as to the nature and causes of specific variations of any of the geophysical phenomena, we do have a number of most interesting and valuable correlations which have now been definitely proved by the unquestionable and repeated data. I have heard no suggestion that earthquakes show any correlations with the solar cycles but just about every other geophysical phenomenon does show some sort of correlation. We are therefore now in a position to begin to trace out the cosmic mes-

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sages of which Dr. Pupin spoke last December in his Presidential address before the American Association for the Advancement of Science.

(4) Data presented from the several lines of investigation lead to the definite conclusion that sunspots are not the fundamental cause of the terrestrial variations and that direct detailed correlations with sunspots cannot be expected. They are indeed an index of the magnetic and electric activities in the Sun which are the actual cause of the terrestrial variations but, in themselves, they are far too crude an index to be considered as having any basic significance. As time goes on, no doubt they will be superseded as a solar index by actual observations of the magnetic and electric conditions in the Sun itself.

(5) There is no task more suitable for serious consideration and promotion by the September 1927 international meeting of the International Geodetic and Geophysical Union than the organization on a world-wide scale of a co-ordinated program of study of the several geophysical phenomena in the various fields covered by this morning's program. It is to be hoped that the recommendation of the American Geophysical Union that the Prague meeting in September undertake as a major topic the correlation of solar and terrestrial phenomena studies will be accepted. If this is done we may well look forward to a new world-wide organization of scientific endeavor along these lines by which the world will enter on a new phase in the study of cosmic phenomena.

Finally, the summaries presented from the various fields of geophysical endeavor show that definite correlations of far-reaching significance have been established in the following diverse fields of observation: (*a*) The various types of solar activity; (*b*) terrestrial magnetism; (*c*) atmospheric electricity; (*d*) meteorological phenomena; (*e*) earth-currents; (*f*) auroras; (*g*) radio wave-transmission.

Although these correlations are in all cases of a partial and tentative nature, they are none the less certain and significant. They indicate that study in these various fields of science in the future can have its value considerably augmented by constant regard to results in the other fields, and particularly results upon the various types of solar variation. The possible phases of solar activity with which correlations may profitably be sought include sunspots, photographic data, heat radiation, electric charge radiations, and various types of ultra-violet radiation and spectro-helioscopic data.

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SECTION OF OCEANOGRAPHY

(Washington, D. C., April 28, 1927)

OCEANOGRAPHIC INVESTIGATIONS ON THE NEXT CRUISE OF THE CARNEGIE

J. P. Ault

(I) TERRESTRIAL MAGNETISM

The next cruise of the *Carnegie*, to be Cruise VII, is planned to begin at Washington early in 1928, is to occupy three years' time, and is to extend around the world over all the oceans. Chief emphasis will be placed on magnetic and atmospheric-electric surveys and investigations since the vessel was designed and fitted primarily for this purpose. The practical and theoretical value of the magnetic investigations already done on the *Carnegie* is testified to by the principal hydrographic establishments of the world and by individual investigators, but the full value of the accumulated data will not be realized without additional observations to determine the secular variation (or progressive) changes in the Earth's magnetism. The chief aim of the magnetic work of the next cruise will be to increase our knowledge of these changes.

In order to make the fullest possible use of previous observations, it is planned to follow as closely as possible the tracks of previous cruises. The map in Figure 1 indicates the route tentatively selected which will be productive of the maximum of valuable data needed. Such a route and program will also give opportunity for securing additional information regarding the distribution of the magnetic elements in some large areas not already surveyed and for investigating regions of pronounced local disturbance, particularly those indicated by the previous work of the *Carnegie* over deep-sea areas, in connection with determinations of ocean depths by echo sounding devices.

(II) TERRESTRIAL ELECTRICITY

The atmospheric-electric program is to be continued and enlarged since the studies and discussions of results already accumulated indicate the value of the work done and point out the need for more data to assist in the solution of the various problems involved. In the further investigations on the origin and maintenance of the Earth's electric charge and of the relation to the Earth's magnetic condition, additional determinations of changes in the values of the atmospheric-electric elements with geographic position are needed. Recent investigations of the pentrating radiation, or of the so-called "cosmic rays," emphasize the

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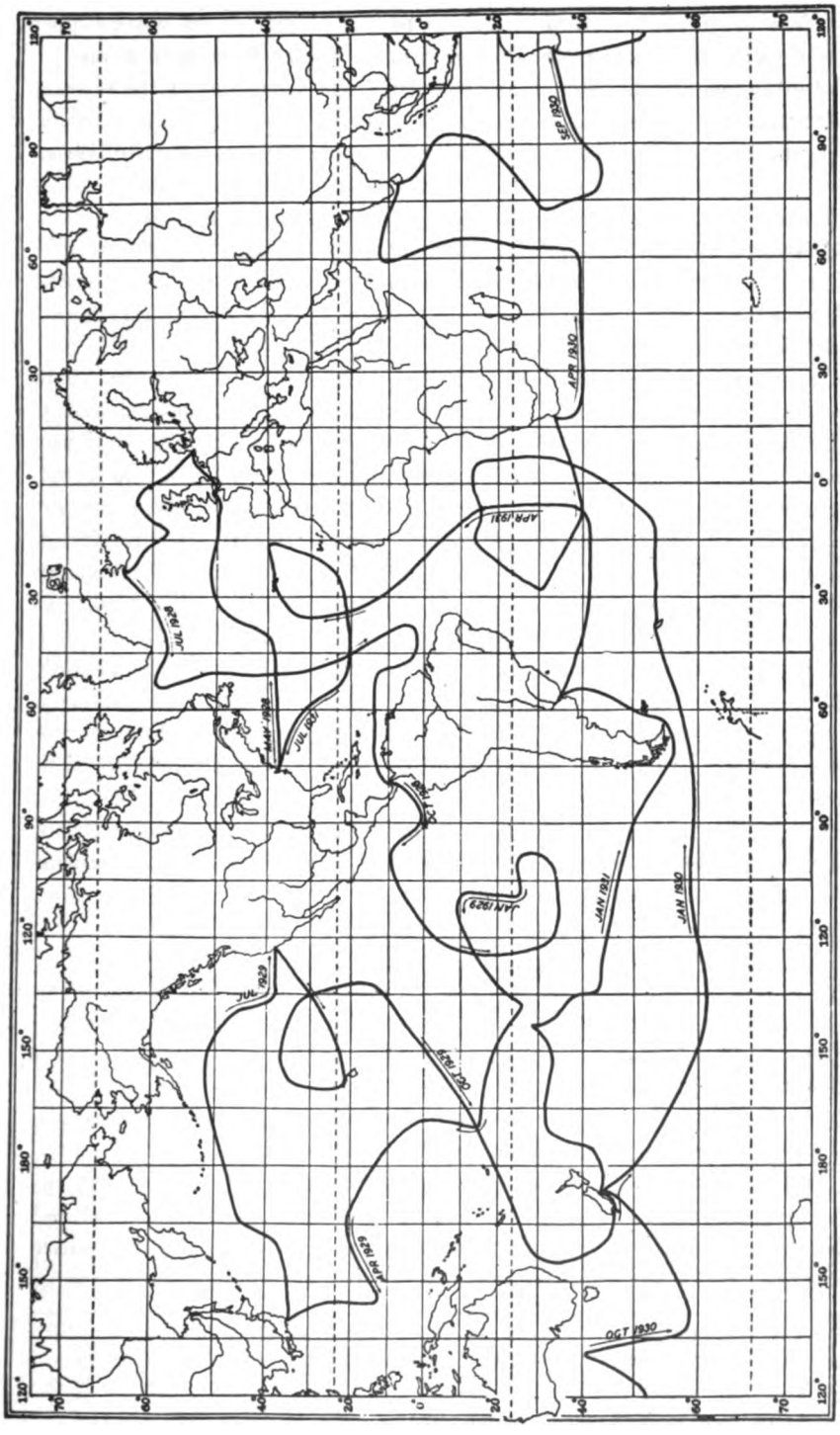

FIG. 1
Tentative route for seventh cruise of the *Carnegie*, 1928 to 1931.

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needs also of additional observations of the ionization of the air over the oceans far removed from possible disturbances from land areas.

Further widely distributed and frequent determinations of the diurnal variations in atmospheric electricity will be obtained in order to settle the question whether such variations progress on the basis of universal time, a deduction first indicated by Mauchly [1] from a discussion of results obtained on the *Carnegie* and later fully confirmed by Sverdrup [2] from observations made on the *Maud* during the Arctic-Drift Expedition. To further improve and control the atmospheric-electric results, dust-count observations of the atmosphere are to be included in the program of electric work at sea.

The important contributions to the study of various geophysical problems which are being made by investigations of the Kennelly-Heaviside conducting layer and of radio transmission and variations with changing magnetic and electric conditions greatly enhance the value of the atmospheric-electric data already collected over the oceans by the *Carnegie*, and indicate cooperative investigations along similar lines for future ocean work. It is planned, therefore, to begin at sea the investigations of the conducting layer and to carry out experiments on the variations of signal-intensity, following methods already in use on land.

Important correlations between earth-current variations and changes in other geophysical and cosmical phenomena, such as solar activity, magnetic disturbances, and polar lights, have been shown from an investigation of observatory records, and the importance of these investigations in the general study of the Earth's magnetic and electric fields warrants the beginning of systematic earth-current observations at sea. Some preliminary experimental work must be undertaken to determine the best methods and instruments for such observations over the oceans.

(III) OCEANOGRAPHY

The Carnegie Institution of Washington has been interested in various problems of oceanography for a number of years through the activities of its various departments and research associates. The vast extent of ocean areas to be covered by the next cruise of the *Carnegie* offers a unique opportunity to secure much-needed data in the science of oceanography in regions which have never been investigated.

With the steady improvement and simplification of methods and instrumental equipment used in making magnetic observations, gained through experience and experimentation, it is now possible to reduce very materially the time occupied in the observational work at sea as

[1] S. J. MAUCHLY, Phys. Rev., N. S., 18: 161-162 and 477 (1921).
[2] H. U. SVERDRUP, Sc. Monthly, 22: 400-410 (1926).

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heretofore done in terrestrial magnetism. Furthermore, for the purpose of determining secular variation, observations of the magnetic elements need not be made so frequently as heretofore for the determination of their distribution, except in those regions not yet sufficiently well surveyed. Thus there will be time for the undertaking of a program of work in more general oceanography.

The following program of oceanographic work is being planned as desirable and practicable for the *Carnegie* under the restrictions of limited space and personnel and the necessity of maintaining a non-magnetic vessel for investigations in terrestrial magnetism.

(*a*) *Physical oceanography,* for the determination of ocean circulation, conformation and topography of oceanic basins, nature of bottom sediments, and of the chemical constituents of sea-water. Temperatures and water samples are to be obtained at depths of 5, 25, 50, 75, 100, 200, 300, 400, 500, 700, 1,000, 1,500, and 2,000 meters every 150 to 200 miles, with occasional work down to the bottom, salinities are to be determined on board ship with the Wenner electric method and checked occasionally by the titration method, surface temperatures are to be recorded continuously, and ocean depths are to be determined by means of the Navy sonic depth-finder as developed by Dr. Harvey C. Hayes. The United States Navy Department is cooperating in this work by the loan of the necessary equipment. For the study of sedimentation, bottom samples will be secured whenever the wire is sent to the bottom for temperature and salinity data.

(*b*) *Microbiology,* to determine the abundance and distribution of plankton and other organisms, such observations being of interest to the biologist as well as being of economic interest in the study of fishes and of other sea food. Shallow water dredging for diatoms and foraminifera will be undertaken, and the quantitative distribution of plankton from the surface down to 100 meters will be determined occasionally by the examination of definite quantities of water brought up by means of a new water-bottle devised by Dr. W. E. Allen of the Scripps Institution of Oceanography. Some study will be made of other marine organisms by means of tow nets, and hauls both vertical and horizontal are to be made from the surface down to a depth of 150 meters. Equipment will be carried also for securing specimens of dolphins and porpoises from regions where no specimens have been secured heretofore. Limited space and time and restrictions as to power and machinery prohibit undertaking any deep-sea trawling or dredging. This work may be taken up during a later cruise when it is hoped that chief attention may be devoted to work in oceanography.

(*c*) *Meteorological oceanography,* to include observations in marine

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meteorology which are of great theoretical and economic importance not only as regards the sea and its life but also as regards their effects in vital relations to continental and coastal regions. One of the most important lines of investigation concerned with studies of temperatures and salinities is the study of the physical interchange between the surface of the water of the sea and the air above it. The determinations of what may be designated "meteorological sections" of the sea to moderate depths and of the air above to masthead height are certain to yield important results bearing on the significance of the seas as distributors of solar heat and on the general circulation of the air over the oceans as an aid in world-wide weather forecasting.

The kinds of meteorological observations at sea, therefore, should include, in addition to temperatures and salinities at the surface and at moderate depths: (1) Temperature lapse-rates from sea-level to masthead; (2) humidity lapse-rates from sea-level to masthead; (3) wind-direction and velocity at different heights; (4) solar and sky-radiation by day and night with cloud systems, rainfall, evaporation, and dust-content and carbonic-acid content of the atmosphere. It is hoped that methods and instruments may be devised for the increased determination of data of these kinds over the great oceanic areas to be covered by the next cruise of the *Carnegie* for the comparison of world weather with solar radiation, for the determination of the rate at which the atmosphere is being charged with water vapor so vital to life on the continents, and for the study of the dynamics of atmospheric circulation over the oceans.

To carry out the program of general oceanographic work outlined above, an additional stateroom is to be provided in the cabin of the *Carnegie* to increase the scientific personnel to seven, the additional man to be especially trained in biology and chemistry. The two lifeboats are to be moved from the quarter deck to overhead platforms amidships opposite the after observatory dome, leaving the quarter deck free for the installation and operation of the necessary equipment for handling the oceanographic work, such as a special nonmagnetic winch, special bronze davits, and racks for mounting water-bottles and deep-sea reversing thermometers. The bronze winch is to be operated electrically by means of an attached motor, the power for which is to be furnished by a generator and 25 horse-power gasoline engine mounted below decks in the engine room. Thus any additional magnetic material will be located from 50 to 75 feet distant from the position of the magnetic instruments, and no disturbance of the magnetic results is anticipated. However, the absence of deviations will be checked carefully, as heretofore, by frequent swings of vessel.

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Two new laboratories are to be constructed on deck, one specially fitted for physical oceanographic, biological, and chemical work, and one fitted with radio and echo sounding equipment. Water samples and biological specimens will be stored below decks.

The difficulties attending the obtaining of deep-sea temperatures and water samples from a sailing vessel are fully appreciated. However, Helland-Hansen and Nansen have carried out similar work with great success on the *Armauer Hansen,* a sailing vessel of only one-half the size of the *Carnegie.* They state that[3] "owing to its special construction the ship is easily maneuvered in such a manner that the line along which the oceanographic instruments are suspended remains in a vertical position throughout the time of observation, even if there is a strong drift caused by wind or current." As a further aid in checking the depths at which temperatures and water samples are obtained, simultaneous use will be made of protected and unprotected thermometers, calibrated for pressure effects, a method used recently with success by the German Atlantic Expedition on the *Meteor.* To avoid rapid and excessive drift of the vessel when hove to in a strong breeze, sea-anchors will be used to check the headway.

It is planned to compute at sea, and publish promptly as the cruise progresses, the pertinent oceanographic data for use of students and investigators of oceanography, as has been done heretofore in terrestrial magnetism. The data to be published include the following results of observations and calculations at various depths: Temperature, salinity, density observed and corrected for compression, oxygen content, hydrogen-ion concentration, specific volume, and dynamic pressure and depth. The dynamic calculations will be made in accordance with the method devised by Bjerknes and as modified by Hesselberg, Sverdrup and others.

The biological and chemical work will be in charge of an observer specially trained in these fields, and the chief effort will be the collection of data and specimens. As complete a preliminary study and report as possible of the results of these investigations will be made as the cruise progresses. Interested organizations will be furnished with water samples, bottom samples, and biological specimens for further study and report.

The Department of Terrestrial Magnetism is indebted to the following institutions and organizations for cooperation in the loan of special equipment or for expert advice in planning the program of investigations: United States Navy Department, loan of latest-type sonic depth-finder complete; Scripps Institution of Oceanography; United States

[3] HELLAND-HANSEN and FRIDTJOF NANSEN. The Eastern North Atlantic. Geofysiske Publikasjoner, 4: (2) 3-4 (1926).

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National Museum; United States Weather Bureau; Museum of Comparative Zoology, Harvard University; School of Geography, Clark University; Geophysisk Institut, Bergen, Norway, loan of various oceanographic equipment; Carlsberg Laboratorium, Copenhagen, Denmark.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE OCEANOGRAPHY OF THE CANADIAN ATLANTIC

A. G. HUNTSMAN[1]

The waters of the Atlantic seaboard of Canada may well be considered the most interesting in the world. Their position midway between pole and equator ensures a maximum of seasonal change. Their western position in the Atlantic Ocean gives an arctic current loaded with ice, and the jutting Newfoundland bank causes this current to debouch suddenly into the poleward-moving equatorial water. The continental shelf is broad and of diversified character, exhibiting a wealth of banks, islands, bays, basins, and deep channels. Also, there is a very heavy inflow of fresh water from land-drainage.

These waters have been well investigated from the standpoint of currents and tides by Dr. W. Bell Dawson. To Dr. Johan Hjort we are indebted for a double comprehensive survey of the Gulf of St. Lawrence and of the waters between Nova Scotia and Newfoundland and out well beyond the continental shelf in regard to temperature and salinity. The work done since his expedition of 1915 has been largely the result of the stimulus furnished by the opening of the general hydrodynamic problem as made by himself and his collaborators.

The coastal water may be considered as basically temperate and of moderate salinity, with summer temperatures of from 6° to 12° C and salinity ranging from thirty to thirty-two per thousand. However, such characteristically boreal water is considerably limited owing to the invasion of the area by other waters of quite different types. Warm coastal water over 12° C in temperature and frequently below thirty per thousand in salinity, occupies in summer many of the shallower portions of the coast, such as the Magdalen shallows of the Gulf of St. Lawrence. Arctic or cold coastal water, mostly below 0° C in temperature and about thirty-two per thousand in salinity, comes down steadily from the north in the Labrador current and is also formed locally during the winter. Such water gives an ice-cold bottom layer rather generally over the more northern banks. Tropic water, about 15° C and over thirty-five per

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thousand, is constantly pressing northward in the so-called "Gulf Stream" some distance outside the shelf. Moving southward below the tropic water is the bottom water of the Atlantic or slope water, about 5° C and thirty-four per thousand, which covers the slope of the continent and penetrates along the bottom into the deeper channels and basins of the shelf.

For an understanding of the changing distributions of the various types of water a knowledge of the circulation is essential. The more pronounced movements in this circulation have become evident through their effects on vessels, through the drift of icebergs, and by direct measurement of the currents. Because much of the circulation has been undecipherable by such means, the Biological Board of Canada, with the cooperation of the United States, Newfoundland, and French government services (arranged through the North American Committee on Fishery Investigations), has put out in the last eight years over 9,000 drift-bottles in an effort to trace the circulation of the waters of the region from the Bay of Fundy on the south to the Strait of Belle Isle on the north. The results reveal a circulation of variable intensity, but showing a definite order—clockwise around isles and shoals and contra-clockwise around basins. The rate of the ultimate movement varies from about two miles per day close to land to about eight miles per day in deep water. The water of the continental shelf has neither a definitely northward trend like the tropic water, nor a definitely southward trend like the Labrador Current and bottom Atlantic water, but moving in a circular fashion shows elements of both, varying in relative proportions from time to time. No drift-bottle has yet been found to have traversed the whole region from north to south, or the reverse. Cabot Strait bottles have attained both the Strait of Belle Isle and the Gulf of Maine, but the reverse has not occurred. Extended movements have all taken place to the other side of the Atlantic, and in a general way the distribution of the bottles from north to south as found on the eastern side of the ocean has corresponded with the order from north to south, in which they were put out on the western side. Bottles put off at the Strait of Belle Isle have gone to Iceland and the north of Norway and a bottle put off from Cape Sable reached Cape Verde, Africa.

The proper elucidation of the factors concerned in the circulation is a matter for the future, but illustrations of the effects of some of them may be given. In the Gulf of St. Lawrence, the prevailing south-west winds produce a somewhat superficial current northward along the west coast of Newfoundland, thus concentrating at the inner end of the Strait of Belle Isle a body of water that has been warmed by exposure to the Sun's rays when spread over the Gulf. The return deep current

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passes southwestward along the other (Quebec) side of the Esquimau channel. Similarly in the Bay of Fundy the warmed surface-water is concentrated at the head, particularly in Minas Channel and basin, but the strong tidal currents mask the wind-circulation, which is nevertheless revealed by the drift-bottles.

When light and heavy water exist at the same level at different places, the Archimedean forces are set into play, and the two waters flow toward each other, the lighter above. The heavy water produced by the mixing of the tropic water with that of the Labrador Current moves south, while the tropic water flows north above it to the mixing region. The light water produced in the estuary of the St. Lawrence by the entering river water flows strongly outward past the Gaspé coast and Cape Breton.

The tidal currents, being oscillatory, are not effective in steadily progressive movements except as modified by the Earth's rotation. That they may in this way be very effective is shown by the circulation through the Strait of Belle Isle. The flooding tide is more pronounced on the north side, carrying Labrador Current water into the Gulf, but the ebbing tide is more pronounced on the south side, carrying out from the Gulf the warm water accumulated at the inner end of the Strait by wind-action. The tides pump the water in both directions through the Strait, the rotation of the Earth serving by deflection to keep the two streams somewhat distinct.

A vertical circulation is likewise effected by the tidal currents, when they flow from deep to shallow water and back again. A most pronounced example of this is to be seen in the estuary of the St. Lawrence, where the deep Laurentian Channel ends rather abruptly near the mouth of the Saguenay River. When the flooding tide comes to the end of the Channel, the deep water (cold and salt) actually comes to the surface and flows back along the south side of the Channel under the influence of the Earth's rotation. The mixing that results from this circulation produces the large volume of comparatively light water, that goes to make up the Gaspé current.

Biological Board of Canada,
Ottawa, Canada.

DYNAMIC OCEANOGRAPHY OF THE GULF OF MAINE

HENRY B. BIGELOW

Within the last few years the mathematical applications of Bjerknes' hydrodynamic theory to ocean-currents have been so simplified by his followers, especially by Ekman, Helland-Hansen, Sandstrom, Hesselberg

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and Sverdrup, and by Smith, that no oceanographer need longer fear to give dynamic consideration to the seas with which he is concerned.

Unfortunately, however, dynamic calculation of circulation in the sea depends on a double assumption, which is seldom—perhaps never—capable of mathematical proof in any individual case; first that somewhere in the picture there is motionless water that can be used as the basis from which to proceed (for currents deducible from the dynamic gradients are relative, not absolute); and secondly, that our choice of a base as the most nearly stationary has been correct. Every opportunity to compare the gradient currents (by whatever method of dynamic expression deduced) with the actual drift observable by direct evidence, as of the current-meter, of the drifts of floating objects, or of the distribution of temperature and salinity, is therefore most welcome. Such a test is now being carried out on the Ice Patrol, by Lieutenant-Commander Smith, in the form of a continuous comparison of dynamic gradients with the drifts of icebergs. And the Gulf of Maine has offered opportunity for attacking the problem along rather a different line, by correlating the dominant circulation with the prevailing dynamic state. This procedure, you will note, is the reverse of that which has been followed in several recent studies, proceeding backwards (if you will) from effect to cause.

As perhaps most of you know, the Museum of Comparative Zoology, and the United States Bureau of Fisheries, have been cooperating in an oceanographic exploration of the Gulf of Maine since 1912. And as our observations on temperature, on salinity, and on the distribution of the plankton have accumulated it has become increasingly clear that the circulation of the Gulf is not purely tidal, as had generally been supposed, but that, underlying the strong tidal currents, the Gulf as a whole is the site of a decidedly definite dominant drift. This, briefly, can best be described as a great anticlockwise eddy, with a movement into the eastern side of the Gulf, circling around its coastline from east and north to west and south, combined with discharges out past Cape Cod and clockwise around the eastern end of Georges Bank.

The regional distribution of salinity, as it appears on horizontal projection, is especially instructive in this partially enclosed coastwise sea, for here the only possible source for water of very high salinity is the open ocean off the mouth of the Gulf. Consequently, any tongue of water much more saline than the rest of the Gulf is the clearest evidence of an actual indraft from off-shore, shortly previous if not at the time. An indraft of just this sort, into the eastern side has appeared repeatedly on the salinity charts, for the upper stratum of water. As an example, the distribution of salinity at forty meters, for the mid-summer of 1914,

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is perhaps the most demonstrative, with a tongue of high salinity circling inward from the offing of Cape Sable past the mouth of the Bay of Fundy to the offing of Penobscot Bay; the successive isohalines indicating (if less clearly), a continuation of this anticlockwise drift around the western side of the basin of the Gulf.

If we descend to the one-hundred-meter level, where the Gulf is entirely enclosed except for the two narrow channels which pierce its offshore rim, the same type of circulation, with a highly saline tongue intruding by way of the eastern channel, has appeared on chart after chart, year after year, exemplified by one for February to March, 1920.

The distribution of temperature is not so good an index to the movements of water within the Gulf, because for most of the year the indraft is not sufficiently different from the basin of the Gulf in temperature to make its presence obvious in this way. But when closely analyzed, with due regard to the seasonal warming and cooling taking place *in situ*, temperature, too, gives evidence of the anticlockwise drift, especially at the season (Spring) when the icy Nova Scotian Current is flooding into the Gulf from the east.

It chances that the Gulf is an especially favorable area for mapping the drift by the distribution of the plankton, because it receives animal and plant immigrants from two dramatically opposite sources, viz., "tropicals" from the warm waters of the so-called "Gulf stream" offshore, and "Arctics" from the icy Nova Scotian Current to the east. And such of these as can only survive for a brief period in the temperatures of the Gulf—too cold for the one, too warm for the other—are the best of natural drift-bottles there. When the recorded occurrence of planktonic immigrants of this transitory category are plotted—tropics and arctics together—it develops that all, irrespective of temperature affinity, are condensed in a band extending inward from the Eastern Channel and Browns Bank, around the periphery of the basin to Massachusetts Bay and the offing of Cape Cod. And the scarcity of brief-lived "tropical" over Georges Banks, where only an odd one has been taken, and in the central part of the basin is especially interesting, because they would naturally be most frequent there, not least so, if they drifted in from the south direct.

The evidence of current-measurements also points to an anticlockwise drift around the Gulf. A considerable number of such measurements have been taken in the eastern side of the Gulf by the Tidal Survey of Canada, and in the western side by the U. S. Coast and Geodetic Survey. When plotted, the non-tidal components of these show a northward component along Nova Scotia toward the Bay of Fundy, an anticlockwise movement within the Bay, a southerly and southeasterly drift past

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Massachusetts Bay and Cape Cod, and so outward past Nantucket Island and Shoals.

Still further to test whether the Gulf is as constantly dominated by an anticlockwise type of circulation as these lines of evidence suggest, we have put out about 1,500 drift-bottles in its western side, since 1922, and the Biological Board of Canada has put out many more in its eastern. In this brief talk I can show you the results of only a few of these; enough, however, I hope to make it clear that the recoveries are reconcilable only on the basis of anticlockwise drifts. Thus drifts from the Canadian series, set out in the Bay of Fundy, tend toward Massachusetts Bay and Cape Cod. Bottles set out off the southern angle of Cape Cod divide, part going out of the Gulf and to the south and west around Nantucket Shoals, but part showing a return drift across the southern side of the Gulf, some to Nova Scotia and the Bay of Fundy but others veering southward around the eastern end of Georges Bank. Bottles set out off northern Cape Cod have again shown easterly drifts, some leaving the Gulf via the route just mentioned, others circling northward to the Bay of Fundy.

Bottles from the offing of Cape Ann have for the most part gone to the Bay of Fundy with some set out close in to the Cape going southward past Cape Cod. Drifts from a line running out from Cape Elizabeth have been similarly divided, the majority crossing the Gulf to Nova Scotia and the Bay of Fundy, a few, however, coasting southward past Cape Cod. And some drifts from the offing of Mt. Desert have also coasted westward, but the majority have gone to the Bay of Fundy after time-intervals averaging about as long as those from the offings of Cape Elizabeth and Cape Ann which is reconcilable with the latter drifts only on the assumption that the Mount Desert bottles, too, circled out anticlockwise, around the basin, en route.

Thus, in summary, clearer proof of the domination of the Gulf by this type of circulation could hardly be asked than results from the cumulative evidence briefly sketched here.

Our next question is, how closely can this type of circulation be correlated with the dynamic state prevailing in the Gulf?

Our method of attack here has been projections of the dynamic contours, at the surface, and at deeper levels, by the methods developed by the Scandinavian oceanographers, and recently explained by Commander E. H. Smith, with whose very clear exposition I hope you are familiar. When it is possible to cover an entire area with a network of stations, this horizontal projection of the dynamic tendency has an obvious advantage over individual dynamic profiles, in its graphic presentation of the prevailing gradients; it also has the advantages of sim-

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plicity and of yielding a picture of a type with which the weather map has made us all familiar. I need hardly add that the dynamic contour charts take into account the regional inequalities of density for the whole column of water surface to bottom, and they are, of course, based on precisely the same hydrostatic principles as are the dynamic profiles.

In the present instance, the contour-lines are drawn for every dynamic centimeter, referred to the part of the picture where the water is heaviest, i. e., the surface lowest. And, for reasons it would take too long to explain here, how closely they stimulate the actual slope of the surface depends partly on how truly applicable, in each instance, is the arbitrary connection which Jacobsen and Jensen have shown necessary between shoal-water stations of different depths.

Such charts are to be interpreted, essentially, just as a weather map is. Thus the water tends, dynamically to drift directly inward toward the "low"; but the deflective effect of the Earth's rotation—to the right in our hemisphere—actually turns the drift nearly parallel to the contour-lines. These may then, for all practical purposes, be interpreted as stream-lines except (and this is a very important exception) as interfered with by the contour of the bottom.

From month to month the contour-charts for the Gulf show an underlying similarity, with the surface highest along shore, lowest somewhere over the basin or the Eastern Channel and outside the edge of the continent.

At the end of the winter the "low" is centered in a trough-like depression over and just within the Eastern Channel, with the surface higher over the Banks on either hand, and rising radially toward the coastline, pointing to an essentially cyclonal (i. e., anticlockwise) eddy around the northern side of the basin, directed eastward around its southern side by the submarine slopes of Georges Bank.

It is not possible here to follow the seasonal changes in detail. In April, as the margin of the Gulf is freshened and lightened by the vernal inrush of land water, the dynamic gradient is steepened along the northern and western coasts, while the "low" flattens out to include all the eastern side of the basin, pointing to a speeding up of the drift westward and southward around the coasts of Maine and of Massachusetts. By May this gradient is still steeper next the land in the western side, building up the "spring-current" to the southwest and south, with which local fishermen are familiar. In summer we have found two interrelated low (cyclonal) centers, one in the offing of the Bay of Fundy, the other over the Eastern Channel and off its mouth. Such a distribution of gradients falls, as a whole, very closely in line with the

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bottle-drifts recorded in summer, eddying around a point in the offing of the Bay of Fundy, and northward along the west coast of Nova Scotia; with an outdraft around the eastern end of Georges Bank. Discussion of events off the seaward slope of the latter, interesting though this would be, cannot be attempted here.

In all these cases, the Archimedean forces, as deflected by Earth-rotation, and as directed by the slopes of the bottom, tend to set the Gulf in cyclonal circulation; they must, in fact, maintain a circulation of this type unless opposed by some overpowering counter force, and there is no such, in the Gulf.

And not only do hydrostatics tend to produce essentially the same type of circulation as is actually recorded by more direct lines of evidence, but the seasonal fluctuations in dynamic contour, and the shifts in the location of the low centers in general reproduce the seasonal variations in the observed drift, especially as regards the speeding up of the longshore current in spring, and the prevailing tendency for the bottles to turn more off-shore from the western side of the Gulf, in summer. And, perhaps most significant, there is no drift clearly indicated by the dynamic contours, of which we do not already have evidence, by bottle-drifts, or by salinity, temperature, or plankton. Without entering here into the question of calculated velocities, I can add that these at least fall within the order of magnitudes demanded by the current-measurements and by the drift-bottle experiments.

Thus we can hardly escape the conclusion that the dominant circulation of the Gulf draws its motive power in large part, at least, from the Archimedean forces set in motion by the regional inequalities in the specific gravity of the water. And this has practical value, as an additional bit of proof that in sea-areas of this sort it is safe to postulate actual drift from dynamic contour, if evidence of a more direct sort is not forthcoming.

However, as Dr. Huntsman has pointed out, another motive force also tends to set the water in circulation anticlockwise around basins in the northern hemisphere, clockwise around shoals—the horizontal tidal oscillations as deflected by the Earth's rotation. In the Gulf of Maine this in general parallels the effect of the dynamic gradients. And it will need much closer analysis than has yet been attempted, to evaluate the relative importance there, of the two.

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OCEANOGRAPHIC INVESTIGATIONS OF THE INTERNATIONAL ICE PATROL

EDWARD H. SMITH [1]

A paper presented before the section of oceanography of the Geophysical Union at its meeting last year gave a brief description of the International Ice Patrol, a humanitarian service that is supported financially by the principal maritime nations of the world in order that life and property on the North Atlantic may be properly safe-guarded. Some phases of the scientific work that is being carried on by the Ice Patrol were described, especially certain investigations in physical oceanography of the ice regions south of Newfoundland where Arctic and Tropical waters meet. The Patrol, in the course of its fourteen years of ocean service, has come to recognize the great value inherent to scientific observations from which practical, useful information may be drawn.

One of the most important problems connected with the ice-work is keeping track of individual bergs that have finally drifted south of the Grand Banks and thence become governed in their movements by the particular features of the circulation prevailing at the time in that part of the North Atlantic. Bergs in such situations are distinct dangers to shipping, and extremely grave menaces, too, if, as it often happens, they are carried southward across the more populous lanes of traffic between the United States and Europe. The simplest and most obvious method of cruising over the ocean area southeast of Newfoundland, fixing the position of the ice from day to day by astronomical sights, is one not always possible. For one thing the ice often becomes widely distributed, and another difficulty is that due to fog. Almost everyone has heard of the notorious Grand Banks fogs and the danger they bring every year to fishermen. The spring and summer when fog envelops the Grand Banks and its surrounding cold waters, is the time when icebergs in greatest number invade this part of the North Atlantic.

The movement of icebergs is almost entirely determined by the ocean-currents, so that next best to actually sighting the ice from day to day, is to have a picture of the current-system into which the bergs are being carried. An accurate map of the currents as they then prevail is, moreover, the key to predicting the drift of icebergs liable to enter the trans-Atlantic shipping lanes. Such hydrographic information also, aside from its forecasting features, is bound to be of value as it throws light on the behavior of drifting ice in general in the northwestern North

[1] Read for Lt. Commander Smith by Capt. A. L. Gamble, U. S. Coast Guard.

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Atlantic. Realizing the practical benefits to be derived from such information, Admiral F. C. Billard, Chairman of the International Ice Patrol Board, in 1924 sent an officer of the United States Coast Guard to Europe in order that the Patrol might learn the newest methods practiced abroad in physical oceanography, particularly as they might be applied to improving the ice service.

The specialized field of physical oceanography, for which the Ice Patrol has found a practical use, has its genesis in dynamics and geophysics contributed by Professor V. Bjerknes, a Norwegian physicist, some thirty years ago. Bjerknes later became interested in applying his theories to a study of the atmosphere, and by so doing greatly improved the art of weather forecasting. It has remained chiefly for a group of Scandinavian oceanographers to apply and develop a workable method for Bjerknes' mathematics to be applied to motion in the sea. As a result of such labor, we are furnished today with a method whereby, if the temperature and the salinity of the ocean are given from known depths and places, the direction and velocity of the currents can be computed and mapped. A pamphlet of some fifty odd pages with illustrations published as Bulletin No. 14 by the U. S. Coast Guard describes this work.

The two Coast Guard cutters *Tampa* and *Modoc,* that are maintaining a continuous guard at the present time in the North Atlantic, are equipped with duplicate sets of oceanographic gear and instruments, concentrating their efforts almost wholly on observations of temperature and salinity of the water. They are each equipped with one electric hoist designed for rapid reeling, six thousand feet of one-quarter-inch wire running rope, two meter-wheels, twelve Greene-Bigelow water-bottles with messengers, twenty-four Negretti & Zambra deep-sea thermometers, six cases citrate bottles with rubber gaskets, and one electric salinity tester. A station team of six men is detailed from each watch and, as the work at all stations is identical, the men soon become very expert. With a well-trained team it is possible to complete all of the observations down to 1,200 meters within one hour, including the time necessary to stop the ship for the sounding and also to get under way. It is important that no more time than absolutely necessary be borrowed from the primary duty of the Patrol—ice scouting.

The critical area upon which the Ice Patrol's attention becomes focused is about 40,000 square miles (an area nearly equal to that of the state of Pennsylvania), off the Tail of the Grand Banks. This locality is sometimes called the gateway to the Atlantic because it is by this point that nearly all of the Arctic ice passes on its journey to temperate latitudes. The currents over this area also are subjected to devious paths

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and a berg may be carried slowly to the westward in one part of the current, while other ice farther off-shore is perhaps swept across the bows of approaching passenger-ships. A practical and comprehensive current-map of this 40,000 square mile rectangle requires a basis of twenty to twenty-five well-distributed stations spaced twenty to thirty miles apart. A vessel capable of maintaining a speed of ten knots is able to perform the observational work, including running time between stations, in about four days. Three times during the ice season of 1926 the Patrol ship on duty off Newfoundland conducted such a survey, and on one occasion the work was extended over an area of 100,000 square miles in the short space of four days. This is the first time in the history of oceanography that deep-sea observations have been treated immediately on board ship and the final results employed for a practical economic purpose. It demonstrates, moreover, what can be accomplished in charting the circulation in other little-known regions.

A policy of the Patrol for the past two years has been to keep an up-to-date current-map of the ice area on board at all times for reference and consultation in carrying out the work. A witness to the vessel making one of its routing current-surveys, sees the business-like side of oceanography. The ship is cruised at ten knots speed or faster over the ocean area it is desired to map, stopping at designated positions only long enough to secure a record of temperature and salinity from seven levels beneath the surface. The number of depths observed is reduced to a minimum without failing to secure an accurate record of the physical character of the water column from the surface down to homogeneous level. The following are the depths which satisfy all practical purposes and which have been adopted as standard for stations seaward of the continental shelf: 0, 25, 50, 125, 250, 450, 750, and 1,200 meters.

It may be rather surprising to some that we have today a real thoroughgoing, practical method of determining currents over thousands of square miles of ocean surface, the task being performed in the relatively short space of a few days—a great advance for, as we all know, current-compilation, especially of an ocean region, has always been a slow, laborious job. The material heretofore has been almost wholly limited to information regarding the behavior of the top few meters of an ocean. On the other hand, by computing the dynamic tendencies at a series of observational stations, and then translating these data into terms of motion, we now include consideration of the entire mass.

Current-data outside continental shelves have been amassed by previous methods from three principal sources: (*a*) ships' navigation; (*b*) floating objects; and (*c*) current-meters. The smooth, gigantic gyrals that are shown dominating each of the hemispheres in the two major

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oceans, have been drawn principally from the navigational records contained in thousands of log-books. The nature of such a compilation, however, admits of a general interpretation only. The success of releasing large numbers of drift-bottles depends to a great degree upon elapsed time and the percentage of recoveries which result from stranding along bordering coastlines. Obviously, an open ocean area does not lend itself to such a form of determinations. Lastly, there are great practical difficulties connected with the proper operation of current-meters in the deep ocean despite the ingenious devices that have been developed in this line of mechanical registration.

The dynamic topographical maps of the sea surface, and of the other observed isobaric surfaces, mark a real, noteworthy progress in the science of oceanography. These charts, drawn as a result of substitution in Bjerknes' formulae, show the contour in dynamic meters of the chosen decibar surface relative to that of a deep decibar surface, which is the one usually employed as a base-plane. If there is no motion on this deep abyssal surface then the contour-lines connecting equal dynamic values at the other depth will be the stream-lines of the gradient current, provided that the accelerating force of friction is negligible. Friction is of small consequence in regions exhibiting a circulatory system of even moderate character and in common gradient currents the effect to accelerate or retard is probably not greater than 0.05 to 0.07 of a knot. This figure is so small that it can be disregarded in practical determinations. All motion is included in the calculations except that due solely to friction of the winds to the surface-layers. Prevailing winds, however, such as the "trades," amassing tremendous volumes of water and initiating gradient currents, are factors included in the calculations. Winds of a temporary character on the other hand—for example, those accompanying travelling depressions—are not accounted for in Bjerknes' formulae, but the effect of this latter class, fortunately, is of a self-compensating nature and they disturb prevailing conditions for brief periods only.

Water or air unqualified by boundaries begins to flow with a tilting of the isobaric surfaces directly in proportion to the steepness of the gradient. Circulation in the sea is almost always at a maximum near the surface, and approaches zero at appreciable depths. Isobaric surfaces, therefore, undulate wider in the upper levels than they do nearer the ocean-bed and so the dynamic topography of the sea-surface can be brought in relief if it is compared with a base-plane located in the abyssal depths.

We accept as a matter of course the topographic features of landscape, but our notions of sea-level are so fixed that it may at first prove dis-

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concerting to contemplate the surface of an ocean as having a prevailing conformation. About one hundred miles directly south of the Grand Banks, the Ice Patrol, however, on several different surveys separated by years, has found a northerly slope to the sea-surface averaging one centimeter per mile. This translated into motion is a current of one knot, which, in terms of mass means approximately two million tons of water per second is being transported eastward between these two geographical positions.

To a student of oceanography the North Atlantic presents some very interesting topographic features. Trace, for example, the outline of our eastern continental shelf, Florida to Massachusetts, and there extended along the edge in similar form we shall find a trough in the sea-surface. This is the zone where oceanic and coastal water of similar specific gravity, but otherwise greatly differing character, mix creating a mass denser than that on either side of it. Looking out across the density-wall into the basin, we find the surface of the water inclines upward, relatively boldly at first, and then less and less obliquely until off-shore a hundred, perhaps several hundreds miles, we should expect to find small changes and the topography without major definition. The North Atlantic aquain (to coin a word), according to this view, has the general shape of a broad, flat plateau, the boundary-slopes of which conform largely to conditions prevailing around the continental edges.

The direct impelling forces of an ocean-current are sought not back to a river-like source, but essentially stretched along the entire extent of flow. The difference in density between coastal and oceanic water (and we use these terms technically), is constantly producing tremendous quantities of energy; power enough to run the world is ceaselessly being converted at these places into the phenomenon of motion. Thus, finally, it is plain to see why the most striking circulation in ocean-basins takes place along the slopes, the edges, and the ridges. The great transitions in temperature and salinity, which are met when crossing from our eastern shelf into deep water, form a veritable zone of energy a thousand miles or more in length, and this is the factor which gives the Gulf Stream its often described resemblance to a river. The energy, moreover, that is being converted into moving the water-particles of the Gulf Stream at a point on the slope, say south of Marthas Vineyard, is just as vital for the identity of the Gulf Stream as the impetus that was imparted to these same water-particles months before when they were in the Carribean.

Three ocean-areas, relatively a very small portion of the North At lantic Ocean itself, have already been surveyed in accordance with Bjerknes' formulae: The Faroe-Shetland Channel, the eastern North

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Atlantic from the European coast west to the 30th meridian, and the waters off the Tail of the Grand Banks where Labrador Current and Gulf Stream meet. One of the main objects which gives stimulus to the *Meteor* Expedition, now in the South Atlantic Ocean, is this "leveling" work of hydrographic engineering. We wish in closing to emphasize the fact that delineating the dynamic topography of the oceans, at least in their main features, is a new and promising field unfolding in physical oceanography.

U. S. Coast Guard,
Washington, D. C.

A STUDY OF THE NORTHERN PART OF THE LABRADOR CURRENT

C. O. Iselin

In the discussion of the Labrador Current which follows, the observation made last summer during the cruise of the schooner *Chance* will be used as a basis. A preliminary report of this trip will shortly appear in *Science*. During the cruise two profiles were run at right-angles to the general trend of the Labrador coast, one just south of Hamilton Inlet and the other off Nachvak Bay which is about sixty miles south of Cape Chidley, the northeastern extremity of the Labrador Peninsula. Besides these physical observations on the Labrador Current, the Expedition made a collection of the flowers and plants from the Torngat Mountains and explored several of the fiords which indent the northern part of the coast. Plankton-hauls and collections of the salmon, char, and cod were also made. Since very little oceanographic work had been done off the northern part of Labrador, the region proved most profitable for a short cruise.

In general, we will limit this discussion to the Labrador Current between the Strait of Belle Isle and Davis Strait, since south of the former is the province of the Ice Patrol and therefore well known, and north of the latter there seems to be no subsurface temperature and salinity observations, which are so necessary in the modern treatment of ocean-currents. Besides the work of the *Chance* there are surprisingly few other subsurface observations from this sector. The *Scotia* in 1913 made three stations in the region of our southern profile, two of these being over the continental shelf and therefore directly comparable. From this point north to Davis Strait the information is limited to a few surface-temperatures and many observations on ice-movements. In 1924, under the direction of Dr. Hjort, a section was run across the narrowest part of Davis Strait which gives a very good picture of both

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the Labrador and West Greenland currents. Since this is the most northerly of the available profiles, it will be described first.

In spite of the fact that at any depth the water is about 3° colder on the western side of the Strait than it is on the eastern side, the isopicnals are caused to slant downward on nearing the Baffin Land shore by the low salinity of all the Labrador Current water. The temperature and salinity profiles show that the water to the west of that having dynamic cause for a southward movement is colder than 0° (except near the surface and below 200 meters) and much of it is less saline than 33.5 per thousand. In the center of the Strait the isopicnals in the upper stratum are forced upward by a core of North Atlantic water (with temperature of about 3.5° and a salinity of about 34.7 per thousand) lying along the outside slope of the Greenland coastal bank. This water acts as the density-wall between the Labrador and West Greenland currents and makes possible the dynamic urge which drives the one southward and the other northward. It will be noted that the gradient for both currents is only slight. Attempts at velocity-calculations are almost worthless since there are so few stations and these vary so much in depth. Yet it is evident that even at this northern point the Labrador Current is driven by the slant of the density-lines *in situ* and is not primarily an overflow of Arctic water. An interesting speculation arising from the profile is whether or not the West Greenland Current plus the land drainage into Baffin Bay does not supply enough water to account for that which is carried out of Davis Strait by the Labrador Current.

We must suppose that the current continues southward hugging the Baffin Land shore until it reaches Hudson Strait where it finds an opening to the left and urged by the rotational effect of the Earth some water undoubtely starts up the north side of the Strait. But in Hudson Strait conditions are very different from Davis Strait. There can be no central core of North Atlantic water to act as a density-wall between the lighter water along each shore since the narrow mouth of the Strait is blocked by the greater part of the Arctic Current which continues southward past it without entering. Therefore the current in Hudson Strait will not arise from gradients set up in the Strait itself, but will be dominated by the outflow of fairly fresh water from Hudson Bay. The importance of this great source of fresh water to the oceanographic conditions along the Labrador coast does not seem to have been enough emphasized. This outflow of water probably results from an actual raising of the surface of the water in Hudson Bay by the inflow of rivers and streams from the immense land-area which drains into it. Hudson Strait is also the first outlet to the right for the counter-clock-

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wise coastal current which has been reported in the Bay itself. What Arctic water does round Resolution Island and starts into Hudson Strait meets then the outflow of water from Hudson Bay, mixes with it, and is probably mostly sooner or later carried out again around Cape Chidley, to continue south as the well-known Labrador Current.

Hudson Strait appears to be an ideal place for tidal mixing, for not only is the tidal range great (thirty feet on the Baffin Land shore) but very strong currents (four to five knots) are reported off Cape Chidley and Resolution Island. The water of Hudson Bay origin cannot differ much in character from the water of the Labrador Current with which it mixes in the mouth of Hudson Strait, for the temperature and salinity profiles made by the *Chance* just south of Cape Chidley shows water of the same character as on Dr. Hjort's profile of Davis Strait.

It is interesting from the temperature-profile of the waters of Nachvak Fiord that more than half of the water in the Fiord is half a degree colder than any of the Labrador Current. This would indicate a gradual warming up of the water over the continental shelf as the summer advances. The deeper waters of the Fiord, being motionless and protected from solar warming by a very stable surface-film of nearly fresh water, probably do not vary at all in temperature. From the mouth of the Fiord to the edge of the continental shelf is a distance of about ninety miles. This region is entirely covered by icy water. Off shore is the warmer water of North Atlantic origin and the most striking thing in this profile is the very abrupt temperature-transition which takes place between the two outer stations where in a distance of about fifteen miles the whole column of water increases about 5° in temperature.

The salinity-profile shows this same abrupt transition between the water of the Labrador Current and the homogeneous mass of the North Atlantic water just outside the edge of the continental shelf. Off the mouth of the Fiord is a region where the water has about the same salinity and temperature from top to bottom. This is probably water which has rounded Cape Chidley and which has been kept well mixed by the tidal current and waves over the many shoals and reefs just north of the profile. As in Davis Strait all the water of the Labrador Current has a salinity of less than 33.5 per thousand.

When we consider the density-profile, a puzzling fact is at once evident. The isopicnals are practically horizontal for the first sixty miles off shore, but outside of this is a narrow band where the dynamic gradient is most pronounced. Is the current confined to only this outer band as is indicated by the profile, or is all the water over the continental shelf moving south? From stations twenty-four miles apart there is a rise of 24.7 dynamic centimeters. This is enough to produce

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a current of about one knot along the outer edge of the icy water. Yet while making this profile we noticed particularly that, although the majority of the bergs were well off shore, a noticeable current existed in the region where the isopicnals are perfectly horizontal. My only suggestion is that possibly the in-shore water gets its movement from the water which is forced out of Hudson Strait as a result of the immense land-drainage into Hudson Bay.

Continuing south again for the next three hundred miles, the Labrador Current flows along the continental shelf constantly mixing with the warmer more saline water along its outer edge, but maintaining its low salinity by the inflow of the many streams along the coast. The characteristic low temperatures persist since as the water flows southward the solar heat cannot penetrate by convection because of the great stability of the water-layers, and the light surface-film itself cannot warm appreciably because of the melting of the many bergs which the Current carries south. Thus we find the Labrador Current off Sandwich Bay nearly the same in volume and character as when it passes through Davis Strait.

The Sandwich Bay temperature-profile shows a much greater volume of water colder than — 1.5° than did the Nachvak profile. This is another indication that the Labrador Current as a whole warms up very slightly as the summer advances because the Sandwich Bay profile was made three weeks earlier in actual time than the Nachvak profile and we must add another four weeks more for the real time interval as at the rate of twelve miles a day it would take the water twenty-eight days to move southward the three hundred and thirty miles between the two sections. Right in-shore and near the surface is a narrow band of very much warmer water. This is the coastal stream always met with by boats sailing near the coast and it consists of the very fresh water which flows out of the many bays. Since this profile is just south of Hamilton Inlet, the comparatively warm coastal stream, really a current within a current, is particularly well developed. A conspicuous gulley in the center of the profile, filled with water 2.5° warmer than that above it, is something of which the few soundings on the chart gave no indication. It is not at all characteristic of the coast in general. Off-shore we notice a narrow band of icy water extending eastward between the depths of forty and one hundred meters, bulging outward the nearly vertical isotherms of the transition region between these depths. Bottom warming is another conspicuous feature of the profile. It is present wherever the water is more than one hundred and fifty meters in depth. The Labrador Current is so very light that it tends to spread out on the surface and when it passes over places that are deeper than two hundred

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meters, warmer water is drawn in from off-shore and a slight mixing results.

The Sandwich Bay salinity-profile shows no important difference from the Nachvak profile except for the great freshness of the warm coastal stream the surface-waters of which have a salinity of less than 20 per thousand. But when salinities and temperatures are converted into densities a very different picture results. The slant of the isopicnals is continued across the whole profile and is not confined to a narrow band as off Nachvak. Thus all the water over the continental shelf, except in the bottom of the gulley, is being driven south by a moderate dynamic gradient and the current is distributed equally across the whole distance. Between two stations one hundred and eight miles apart there is a rise of 25.3 dynamic centimeters. This is almost exactly the same rise which was present off Nachvak in a distance of twenty-four miles.

This broadening and slackening of the gradient is well brought out by the horizontal projection of the dynamic forces. The five-dynamic-centimeter contours of only two sections make it, of course, impossible to represent with any certainty the course of the dynamic isobaths along the middle part of the coast. The possible course, however, of the strength of the Current may be based on observations on the distribution of bergs. These tended to be strung out in long rows well off-shore in the region off Nachvak and more scattered off Sandwich Bay. Along the middle part of the coast, especially near Cape Mokkovick and Cape Harrison, great numbers of bergs were aground close to the shore. On the other hand, the coast near Hamilton Inlet and also for the first one hundred and fifty miles south from Cape Chidley was comparatively free of ice.

Turning now to the velocity of the Current along the Labrador coast we find that a good average figure for the whole length of the coast is ten to fourteen miles a day. Off Nachvak, where as we have seen the gradient was steep over the edge of the continental shelf, velocity-calculations give as much as twenty-three miles a day for a narrow band, but down off Sandwich Bay velocity-calculations give at the most ten miles a day. In navigating I found that the Current was generally slightly stronger than this. The drift of the *Polaris* floe-party in March and April, 1873, averages fourteen miles a day from off Hudson Strait to a point off Hamilton Inlet where their daily average decreased to about eight miles a day until they were rescued. At this time of year the prevailing northwest winds probably accelerated their drift, while the Current itself was probably slightly slower than in summer for the main force which maintains the low density of the coastal water, that is land-drainage, had not yet come into full operation. We must expect a sea-

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sonal fluctuation in the strength and volume of the Current depending on the liberation of great quantities of fresh water each spring all along the coast.

Finally, what is the state of the warmer, more saline, North Atlantic water outside the edge of the continental shelf? Is this moving south also as most current-charts for the North Atlantic indicate? Light is thrown on this question by a profile made by the *Scotia* in 1913 just south of the Strait of Belle Isle. This consists of six stations and extends about five hundred miles off-shore in a line roughly perpendicular to the general trend of the coast. When the densities for the profile are calculated and plotted, a most interesting fact is at once evident. Just off the edge of the continental shelf the isopicnals slant upward indicating a southerly current about one hundred miles wide, but for the next three hundred miles off-shore the isopicnals at all depths are perfectly flat showing that if the warmer, more saline, off-shore water was moving south at all, it was not through dynamic forces. There is no reason to think that this same condition does not exist further north where the *Chance* sections were too short to include the flattening out of the density-lines. The Labrador Current is then primarily an icy stream over the continental shelf which flows southward inside of the motionless homogeneous mass of North Atlantic water which is present along its outer edge even to a point north of Davis Strait.

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RECENT PROGRESS IN THE DYNAMICAL OCEANOGRAPHY OF THE NORTHEASTERN PART OF THE NORTH PACIFIC OCEAN

GEORGE F. MCEWEN

INITIAL EXPLANATIONS OF COLD WATER OFF THE WEST COAST OF NORTH AMERICA

Numerous observations distributed through a period of many years have established the presence of abnormally cold surface-water contiguous to the Pacific Coast of North America. The results of several different attempts to account for this interesting phenomenon without the aid of an adequate dynamical basis have been published. Some of the conclusions thus reached are briefly reviewed here.

(1) The Japan Current in its slow and interrupted flow eastward is partly deflected to the south from Southern Alaska. It loses its heat as it flows southward and produces the fogs and rains in the region of Washington and Oregon. By the time it reaches San Francisco it is a cold current simply because it is intruding into a normally warmer area.

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(2) A cold Arctic current flowing southward is powerful enough to alter materially the direction of the Japan Current as far south as Point Conception in latitude 34° north. Thus the warm Japan Current is prevented from washing the shores of North America north of Point Conception, but from here on it flows over the cold current. Both this cold in-shore current and the Japan Current flow southward and produce a narrow eddy-current flowing northward next to the shore.

(3) The warm Japan Current becomes so diffused in its passage eastward from Japan as to be ineffective before reaching North America, and the Alaskan glaciers are not extensive enough to materially cool the adjacent waters. The extensive Antarctic continental glacier cools the ocean water which sinks to the bottom and is forced northward by the supply accumulating behind it. This bottom current increases in velocity as it flows northward from the equator through a contracting section. Thus its velocity is doubled at the latitude of Vancouver's Island and it is so forced against the shore by the Earth's rotation that it rises to the surface and flows southward, having no other outlet. It is held against the coast in opposition to the westward deflecting force due to the Earth's rotation by the eastward pressure of the northward-flowing bottom current.

(4) Since observations indicate narrow belts of alternately warm and cold water, directed to the west of the coast, the hypothesis of a surface-stream flowing south from a region of low temperature is untenable. Moreover, the coldest part of the cold-water belt is at latitude 40° north near Cape Mendocino. Thus the only explanation involves an upwelling of cold water from adjacent ocean-depths. Such an upwelling results from a general drift of the bottom-water eastward in agreement with the observed direction of the surface-drift. On striking the slope of the continental shelf, this eastward drifting bottom-water is deflected upward. Local variations in the coastal water-temperatures are due to submarine valleys and other irregularities of the continental shelf.

RELATED OCEANIC AND ATMOSPHERIC CONDITIONS IN THE NORTH PACIFIC

The average or typical conditions of wind, weather, and barometric pressure, over the ocean for each month are shown on "Pilot Charts" prepared by Governmental weather bureaus and navy departments from observations furnished by navigators. The typical seasonal variation of the barometric pressure-gradient between the North Pacific "High" and the coast at latitude 35° north, and the typical seasonal variation of the ocean-winds between the center of the "High" and the coast have been found from such charts. The surface-temperature of the sea that

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would correspond to latitude and time of year in the absence of the disturbing effect of oceanic circulation, called the "normal" temperature, has been approximately determined from compilations of millions of temperature-observations. Typical monthly surface-temperatures have been found from a series of daily in-shore observations near the town of Hueneme at latitude 34° 09′ north begun in 1919 by the Scripps Institution. Monthly averages of the estimated normal for latitude 34° 09′ north minus actual temperatures have been found. [These values are all presented in Table 1, columns (1), (2), and (3), respectively.]

TABLE 1—*Typical seasonal variation of the barometric pressure-gradient, the ocean coastal winds, and the reduction of the surface coastal temperature below the "normal" value for the latitude 34° 09′ North*

Month	(1) Pressure-gradient in 1200 miles	(2) Ocean winds velocity per hour	(3) Temperature-reduction at the surface
	mm	*miles*	°
January	3.05	8.5	1.8
February	3.90	9.7	1.3
March	4.94	11.2	1.5
April	5.70	12.8	2.6
May	6.32	14.3	3.7
June	7.00	14.4	5.4
July	7.5	16.5	6.2
August	7.8	16.5	6.1
September	7.73	16.2	5.8
October	7.0	12.1	5.0
November	5.76	9.4	3.4
December	3.05	8.1	1.4
Averages	5.81	12.48	3.68

The table shows that all three quantities, pressure-gradient, ocean winds, and reduction of surface-temperatures, vary in the same way throughout the year. All reach a maximum value in August and a minimum value in January. The relation between the pressure gradient and accompanying winds accords with a well-known principle of meteorology based upon an equation between the pressure-gradient and the deflecting force due to the Earth's rotation and the wind-velocity at right-angles to the gradient. What is the physical basis of the indicated relation of the temperature reduction to the wind?

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EKMAN'S DYNAMICAL THEORY OF WIND-DRIVEN CURRENTS

About twenty-five years ago Dr. Fridtjof Nansen's observations on winds and surface-drift in the North Polar region revealed a definite tendency of the current to deviate to the right of the wind. At his suggestion Dr. V. W. Ekman, a mathematical physicist, formulated mathematically the problem of wind-driven ocean-currents, using the general equations of the motion of a viscous fluid, in which the deflecting force due to the Earth's rotation was included. Also, he replaced the coefficient of viscosity by a coefficient of "turbulent friction," the value of this coefficient being determined by applying the solution of his formal equations to field data. His elaborate analysis of the problem, including the effects of latitude, depth of water, neighboring coasts, and topography of the bottom, has furnished oceanographers with the first mathematical equations applicable to this problem that rest upon an adequate physical basis. Certain of his conclusions are briefly summarized here:

(1) The surface current caused by wind tends to be deflected to the right of the wind through an angle of 45° in case the ocean is very deep and in the absence of coastal barriers.

(2) The velocity of the resulting current varies directly as the wind-velocity and inversely as the square root of the sine of the latitude. In general the current-velocity is roughly two per cent of the wind-velocity.

(3) The current at any level below the surface tends to deviate more to the right, the lower the level, and its speed decreases. It averages only three or four per cent of its surface-value when the direction is 180° from that at the surface.

(4) The resultant momentum of this layer of water is directed at right-angles to the wind.

(5) A difference in level at the surface resulting in a pressure-gradient will cause a current to flow at right-angles tc the gradient except near the bottom where the direction turns more in line with the gradient.

(6) The thickness of this bottom-layer within which appreciable turning of the velocity in the direction of the gradient occurs is about the same as the thickness of the upper layer within which the velocity turns through an angle of 180°. This thickness, called the "depth of frictional influence," varies directly with the wind and inversely as the square root of the sine of the latitude, and averages roughly one hundred meters.

(7) As the depth of the sea decreases from this "depth of frictional resistance" the frictional effect becomes of relatively greater importance than the effect of the deflecting force. The current tends to deviate less from the direction of the pressure-gradients or frictional drag of the wind at the surface.

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COLD COASTAL WATER DUE TO UPWELLING EXPLAINED BY EKMAN'S THEORY

Observations show that, except for one or two months in the winter, the ocean-winds along the Pacific Coast of North America from about latitude 20° to 45° blow towards the southeast or southwest. This agrees with the general relation between winds and isobars. Accordingly, there is a component of the wind parallel to the coast and directed to the south. Therefore, according to Ekman's theory, surface-water is carried along the coast and to the right (to the west) of the coast by this component. This gives rise to a lowering of the water-level near the coast and an elevation to the west. Hence, along the bottom, the pressure of the water decreases toward the coast. Accordingly, near the bottom the water flows toward the coast and to the south thus replacing the water that is being removed from the layer near the surface. In between the surface-layer and bottom-layer the flow is directed to the south and parallel to the coast. The resulting replacement of warm surface-water by cold bottom-water upwelling at a rate proportional to the wind-velocity explains why the reduction of surface-temperature varies in the same way throughout the year as the intensity of the pressure-gradient out from the Pacific "High" and as the corresponding ocean-winds.

RELATION OF THE SUMMER PACIFIC "HIGH" TO IN-SHORE TEMPERATURES DURING A TEN-YEAR SERIES

There is strong evidence that the intensity of the Pacific "High," the velocity of the ocean-winds, and the reduction of surface-temperature below its normal value vary throughout the season in accordance with established physical principles. It is commonly known that this seasonal cycle obtained by combining available data pertaining to a sufficiently long period of years to obtain a characteristic or typical result does not exactly fit any individual year. Each year departs in a different way from the average, but a correlation between the departures of the related quantities should be revealed by data tabulated with reference to each of a period of years. The Imperial Marine Observatory at Kobe, Japan, has published monthly averages of sea-temperatures, barometric pressures, and cloudiness corresponding to five-degree quadrangles, based upon the meteorological logs of the Japanese merchant marine, beginning with 1916. Daily surface-temperature observations at the Scripps Institution pier, La Jolla, California, are available for the same period. A provisional index of the pressure-gradient for the four-month interval July to October was obtained by averaging the four highest pressures and subtracting from this average the average pres-

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sure at the coast for the same interval for the quadrangles between latitude 30° and 40°. In Table 2 the departure of this index from the mean for the period 1916 to 1925 is tabulated against the departure of the ocean surface-temperatures at La Jolla for the interval August 1 to October 15 from its average. Also, the departure of the seasonal rainfall for twenty stations from San Diego to Yosemite expressed in per cent of the average for the period is tabulated in the last column. As would be expected, the signs of the departures of the pressure-index are opposite to those of the temperature-departures.

The temperature-departures for the interval August 1 to October 15 indicate in advance the seasonal rainfall for the interval July 1 to July 1 of the following year. The signs of the rainfall-departures are opposite to those of the temperature-departures, except for the year 1924. In this year the pressure-departure and temperature-departure were both negative, contrary to expectations and to the general relation indicated by the table.

TABLE 2—*Departures of pressure-gradient from the Pacific "High" eastward, July to October; departures of La Jolla ocean surface-temperatures, August 1 to October 15; departures of seasonal rainfall in per cent of the average, 1916–25*

Year	Pressure-gradient per 1200 miles	Ocean surface-temperature departures at La Jolla	Seasonal rainfall-departures for Southern California
	mm	°	*per cent*
1916	.71	−1.1	14.5
1917	− .22	1.3	−14.3
1918	−1.42	1.8	−18.6
1919	4.51	−0.8	9.7
1920	−1.19	0.3	5.0
1921	.....	−1.1	51.2
1922	0.14	0.3	4.6
1923	1.29	2.0	−33.8
1924	−1.92	−2.0	5.2
1925	0.66	−0.6	6.0

COMPUTATION OF UPWELLING VELOCITY FROM THE DIFFERENCE BETWEEN OBSERVED AND NORMAL SERIAL TEMPERATURES

The evidence of the presence of currents directed upward from the bottom along the California coast accounting for the low coastal temperatures suggested the following problem. Assume that the reduction of temperature at all depths is due entirely to upwelling. Compute the

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velocity of upwelling that would be necessary to produce the observed surface-temperature reduction below its normal value, corresponding to each month, assuming the rate of upwelling to be proportional to the component of the wind-velocity parallel to the coast found from the Pilot Charts. Below the depth of about fifty meters the Fourier equation of heat-conduction in solids or indisturbed liquids may be applied if the usual coefficient of conductivity is replaced by a larger virtual coefficient corresponding to the conditions of mixing or turbulence in the sea. Add the term

$$\left(-w\frac{\partial\theta}{\partial y}\right)$$

to the right side of the Fourier equation where w is the velocity of upwelling, θ is the temperature, and y the depth. The rate of change of temperature in terms of the virtual coefficient of conductivity, the vertical temperature-gradient, and the vertical velocity thus found are expressed by the differential equation

$$\frac{\partial\theta}{\partial t} = C\frac{\partial^2\theta}{\partial y^2} - w\frac{\partial\theta}{\partial y}$$

The observed value of the component of the ocean-wind parallel to the coast off San Diego can be well represented by a simple periodic function of the time, and the upwelling velocity w should be proportional to this periodic function. The solution of this equation was fitted to the observed monthly temperatures at a series of depths off San Diego. The average annual value of the upwelling velocity thus found was thirty-one meters per month. For a surface-layer of about ten meters thickness, the same equation may be used except for the first term in the right-hand member. This must be replaced by two terms, one denoting the rate of absorption of solar radiation and the other which is approximately a linear function of the temperature, denoting the rate of loss of heat by evaporation and back radiation. Using a deduction from the previous result that the temperature-reduction is proportional to the length of the interval and the temperature-gradient, the temperature was computed for each month at the ten-meter level. Combining these values with the temperature-reduction within the upper ten-meter level estimated from the equations that correspond to that level, the theoretical surface-temperature was found for each month. Table 3 presents the computed and observed temperatures at the forty-meter level, the predicted surface-temperatures, the observed surface-temperatures, and the normal surface-temperatures.

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The agreement between the computed and observed temperatures at the forty-meter level illustrates how the formula for temperatures from that level to the bottom represents the observations, the constants being determined by fitting the formula to the observations. The agreement between the predicted and observed surface-temperatures is a severe test of the whole theory since the computations did not involve the observed surface-temperatures.

TABLE 3—*Observed and computed monthly temperatures at the forty-meter level, at the surface, and the normal surface-temperature off San Diego*

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual means
	°	°	°	°	°	°	°	°	°	°	°	°	°
Computed temperature at 40 meters...	13.4	11.9	10.6	9.9	9.9	10.6	11.9	13.4	14.7	15.5	15.5	14.7	12.7
Observed temperature at 40 meters...	13.4	13.4	13.0	11.0	10.5	10.8	11.8	12.7	14.8	16.8	15.4	14.0	13.1
Computed temperature at surface.....	15.2	14.6	14.5	15.2	16.4	17.7	18.8	19.5	19.5	18.8	17.7	16.3	17.0
Observed temperature at surface.....	15.0	14.3	14.6	15.2	16.1	17.8	19.7	20.6	20.2	18.8	16.8	15.5	17.0
Normal temperature....	16.5	15.7	15.9	17.1	18.9	20.9	22.4	23.2	23.0	21.9	20.1	18.1	19.5

An independent estimate of the average annual velocity of upwelling was made from the salinity-gradients, both horizontal and vertical, and the rate of evaporation at the surface. Since mean annual values only are considered, all conditions may be regarded as independent of the time. Therefore the total amount of water in a given volume, and the total quantity of salts in solution remain constant. Consider a rectangular volume from the surface down to a depth less than thirty meters (the depth of minimum salinity) having two of its parallel faces parallel to the coast line. Water will flow through the lower face and through the vertical face nearest the coast-line, also owing to evaporation at the surface it will flow out through the upper face. The resultant effect is a constant volume of water in the parallelopiped. The water that flows in at the base has the lowest salinity. The water that flows in through the face nearest to the coast has a different salinity

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from that which flows out through the face farthest from the coast. Parallel to the coast the salinity-gradient is negligible. At the upper surface fresh water leaves owing to evaporation but no salt is removed in this way. Expression of the fact of the constancy of the amount of water and of the amount of salt in this volume mathematically, results in an equation from which the vertical velocity can be computed. The value thus found agreed well with that estimated from the temperature-distribution.

HORIZONTAL SURFACE-CURRENTS COMPUTED FROM THE DIFFERENCE BETWEEN OBSERVED AND NORMAL SURFACE-TEMPERATURES

The quantity of radiant energy that passes through a unit area of the sea and is absorbed by a thin layer of water varies directly as its thickness and is assumed to be proportional to the amount of radiant energy that reaches a horizontal surface. Energy leaves this layer because of back-radiation and evaporation at a rate approximately proportional to the temperature-departure from a constant corresponding to the latitude. The time-rate of change of the energy in this volume equals the difference between the rate at which it enters and leaves. If the water flows horizontally, and there is a pressure-gradient in line with the direction of flow, the product of this gradient by the velocity is proportional to the rate at which energy enters or leaves the volume due to the current.

The average of surface-temperature corresponding to a given circle of latitude tends to approximate the "normal" for that latitude as the number of observations increases, if they are so distributed as to be representative. The "normal" temperature is defined as the temperature that would result if there were no current. From estimates of such mean annual temperatures, the seasonal range of temperatures, and solar radiation an equation has been derived between the temperatures, observed and normal, at two points along a stream-line, its angle with the meridian, and the velocity of the current. The relation between the observed and normal temperatures for only one point, the observed and normal gradients at that point, and the velocity have also been derived, and expressed in the form of an equation. The first equation is

$$e^{-R} = \frac{\theta - \theta_n - G\,(\cos\psi)\,(z - z_o)\,U}{\theta_o - \theta_{no}}$$

where

$$R = \frac{k}{H}(z - z_o), \quad U = \frac{1 - e^{-R}}{R}$$

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ψ is the angle of the stream-line with the meridian, G is the normal horizontal temperature-gradient along the meridian, k is a physical constant depending upon the rate of cooling, H is the horizontal velocity, $(z - z_o)$ is the distance measured down-stream from the point where the observed temperature is θ_o and the normal is θ_{no} to the point where the observed temperature is θ and the normal is θ_n. The units are the month, the length of a degree at the equator, and Centigrade temperatures. The value of k is approximately 0.20, and G equals about 0.5. Denoting by G_o the observed gradient along the stream-line the second equation is

$$H = \frac{k\,(\theta_n - \theta_o)}{G_o}$$

The first equation is preferable, but the second may be used in case the data required in the first are not available. In general it is difficult to

TABLE 4—*Computation of surface-currents from surface-temperatures and winds based upon observations furnished by the U. S. Destroyer Fleet from San Diego southwest, March 1925*

Lat. of center of stream-line	Temperature		Angle ψ	Wind per hour	Computed current-velocity per hour		
	Obs'd θ_o θ	Normal θ_{no} θ_n			From temp.	From wind according to	
						Marmer	Ekman
°	°	°	°	*miles*	*mile*	*mile*	*mile*
25.5	17.8	20.0	241	7	.33	.10	.15
	18.1	20.7					
27.5	16.4	18.6	155	8	.14	.11	.15
	17.5	20.0					
27.5	17.4	19.4	197.5	18	.09	.25	.33
	18.4	20.7					
28	16.55	18.6	246	11	.15	.15	.20
	17.4	19.4					
29	15.5	18.2	120	13	.20	.20	.23
	16.2	19.0					
30	14.85	16.5	164	11	1.80	.17	.20
	15.4	18.5					
30	14.9	16.9	229	8	.08	.13	.14
	15.9	18.4					
31	14.4	15.7	172	11	.68	.18	.19
	15.4	18.2					

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determine G_o. The result of applying these equations to data supplied by the U. S. Destroyer Fleet in March 1925, and by the U. S. Navy Transports since December 1925 are presented in Tables 4, 5, and 6. All temperatures were averaged by months and quadrangles, 30′ on a

TABLE 5—*Computation of surface-currents from surface-temperatures and winds based upon observations furnished by U. S. Navy Transports between Panama and Seattle, December 1925 to May 1926*

Date	Lat. of center of stream-line	Temperature		Angle ψ	Wind miles per hour	Computed current-velocity per hour		
		Obs'd θ_o θ	Normal θ_{n_o} θ_n			From temp.	From wind according to	
							Marmer	Ekman
	°	°	°	°	*miles*	*mile*	*mile*	*mile*
Dec. 1925	18.2	29.4	24.7	316	6	.38	.07	.15
		28.8	24.3					
	24.0	25.6	23.25	322	6	.18	.08	.14
		25.0	22.3					
Jan. 1926	30	16.6	17.9	182	9.5	.10	.14	.17
		17.4	19.4					
Mar. 1926	33	19.7	15.9	301	13	.62	.22	.22
		18.3	14.1					
	33.5	19.7	15.9	301	13	.21	.22	.22
		18.3	14.1					
	35	19.3	14.6	301	.....	.07	.....	.....
		16.1	12.75					
May 1926	22.5	20.0	23.5	140	11	.....	.13	.22
		24.4	24.4					
	31.5	17.5	19.4	135	13	.20	.22	.22
		17.8	20.7					
	34.7	13.3	16.55	.....	.....	.05	.....	.....
		15.6	17.7					

side. A uniform length of three degrees was selected for the portion $(z - z_o)$ of the stream-line, and the resultant of all winds corresponding to this part was computed. The corresponding current was assumed to be directed at an angle of 45° to the right of this resultant according to Ekman's theory. The intensive data in the region from San Diego to a position about eight hundred miles southwest, furnished by hourly observations from the Destroyer Fleet, averaged about forty to fifty ob-

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servations per quadrangle, while the Transport data along the coast from Panama to Seattle averaged about one tenth as much. The data and results of current computations are summarized in Tables 4, 5, and 6.

TABLE 6—*Computation by second method of surface-currents from surface-temperatures and winds based upon observations furnished by the U. S. Navy Transports between Panama and Seattle, January and February, 1926*

Date	Lat. of center of streamline	Temperature			Angle ψ	Wind per hour	Computed current-velocity per hour		
		Obs'd θ_o'	Normal θ_n	Gradient G_o			From temp.	From wind according to	
								Marmer	Ekman
	°	°	°	°	°	*miles*	*mile*	*mile*	*mile*
Jan. 1926	10	26.3	25.45	−.157	281	18.9	.10	.17	.62
	14.8	26.0	24.0	−.425	259	14.2	.01	.14	.35
	18.5	26.73	23.0	−.697	187	13	.....	.14	.28
Feb. 1926	10.5	25.6	24.9	−.181	285	8.8	.07	.08	.27
	14	26.8	23.8	−.08	180	20	.72	.20	.49

HORIZONTAL SURFACE-CURRENTS COMPUTED FROM WINDS ACCORDING TO MARMER AND EKMAN'S THEORY

The ratio of current to wind was found empirically by Marmer from about 60,000 observations from lightships between San Francisco and the Columbia River. Winds were estimated hourly and currents were measured by a pole allowed to float from the ship through the fixed distance, one hundred feet. Contrary to Ekman's theory this ratio was found to decrease as the latitude decreased. It was found to increase slightly with a decrease of the wind-velocity. The currents computed from the ratio thus found, extrapolated to the corresponding latitudes, are entered in columns (7, 8, and 9) of Tables 4, 5, and 6. The currents computed from the winds, according to Ekman's theory are entered in columns (8, 9, and 10) of Tables 4, 5, and 6. These are seen to agree well on the average with those estimated from the temperatures, thus confirming the conclusion that the winds are the main cause of these coastal currents. In order more readily to compare estimates of the ocean-currents by each of the three methods the values are arranged according to the order of magnitude in Table 7.

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TABLE 7—*Estimates of current-velocities taken from tables 4, 5, and 6, arranged in their order of magnitude*

Method	Current-velocities in mile per hour										
Temperature....	1.80	.72	.68	.62	.38	.33	.21	.20	.20	.....	.....
Marmer..	.25	.22	.22	.22	.20	.20	.18	.17	.17	.....	.....
Ekman...	.62	.49	.35	.33	.27	.23	.22	.22	.22	.....	.....
Temperature....	.18	.15	.14	.10	.10	.09	.08	.07	.01	0.19	0.26[a]
Marmer..	.15	.14	.14	.13	.11	.10	.08	.08	.07	0.16	0.16
Ekman...	.20	.20	.19	.17	.15	.15	.15	.14	.14	0.21	0.25

[a] Mean from the temperature-method excluding the two extremes 1.80 and .01.

HORIZONTAL SURFACE-CURRENTS COMPUTED BY MEANS OF THE BJERKNES CIRCULATION THEORY

Currents caused primarily by differences in specific gravity can be computed from serial temperatures and salinities at stations whose connecting lines are approximately perpendicular to the flow, by means of special methods based upon the hydrodynamical researches of V. Bjerknes. Also, there is reason to believe that the combined effect of winds and agencies tending to produce pressure-gradients by their effects on the distribution of specific gravity may be taken into account by applying the "Bjerknes method" in the usual way.

Off Lower California in latitudes 23° to 28°, assuming no current at the bottom, a flow to the south across each of the three sections by the Bjerknes method was found to be 0.04, 0.72, and 0.27 knot. From surface-temperatures, the corresponding velocities were found to be 0.11, 0.07, and 0.07. In latitude 43° the Bjerknes method indicated a flow of 0.03 to the south, and the temperature-method indicated 0.05.

COMPUTATION OF JAPAN CURRENT NEAR LONGITUDE 175° EAST FROM SURFACE-TEMPERATURES

A few estimates of surface-velocity in the Japan Current were made from surface-temperatures in quadrangles (41° to 45°) north, (166° to 170°) east, and (43.5° to 47.5°) north, (176° to 180°) east, the distance between being 7.46 degrees. The results of seven different computations are presented in Table 8.

The variability is rather large, but the median value of one-half mile per hour agrees well with that found by tracing temperature-departures across the Pacific from Japan.

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TABLE 8—*Computation of current-velocities in the Japan stream from temperatures in quadrangles (41-45)N, (166-170)E and (43.5-47.5)N, (176-180)E (Distance between centers equals 7.46 degrees)*

Date	Lat. of middle of stream-line	Temperature		Angle ↓	Current per hour
		Observed	Normal		
	°	°	°	°	*miles*
Mar. 1919	44.2	1.4	7.7	71	.19
		3.9	6.3		
Oct. 1919	44.2	10.0	15.3	71	2.03
		10.3	13.7		
May 1920	44.2	7.4	11.3	71	.51
		8.0	9.8		
Nov. 1920	44.2	6.3	13.1	71	1.47
		6.8	11.6		
Mar. 1922	44.2	5.0	5.4	71	.41
		7.7	6.3		
Mar. 1923	44.2	1.5	7.7	71	.25
		3.5	6.3		
Apr. 1925	44.2	4.3	9.1	71	.98
		4.7	7.7		
Median (longitude 173° east)					0.51

In general, as illustrated by this paper, there are several different indirect methods of determining oceanic circulation from observations that can be made in any part of the ocean without special equipment. Others require intensive serial collections and observations at selected stations with the aid of special equipment. Methods appropriate to all available data should be applied in order adequately to check the results.

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OCEANOGRAPHY AND OIL DEPOSITS

PARKER D. TRASK

I think we all feel a certain amount of satisfaction whenever a practical application of a science is found. In work on a project endowed by John D. Rockefeller and carried out under the auspices of the American Petroleum Institute, the science of oceanography is being called upon to aid the oil industry. The purpose of this project is to study the conditions under which the sediments that in the future will be possible

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source-beds of petroleum are forming today. The work relates to the solution of the question of the origin of petroleum and should afford essential information that will aid the geologist in his increasingly more difficult task of finding new oil-pools.

Since most of the source-beds of present day oil-fields are marine in origin, it is seen that this project is closely associated with oceanography and hence is a very practical application of that science. Although attention is concentrated on the material at the bottom of the sea, nevertheless the problem is directly associated with all that goes on in the water above.

The work is being conducted under the supervision of a committee composed of Dr. W. van der Gracht (Chairman), Vice-President of the Marland Oil Co., Dr. T. Wayland Vaughan, Director of Scripps Institution of Oceanography, and Dr. Austin H. Clark, Oceanographer of the U. S. National Museum.

In attacking the problem it is necessary, first, to discover what sediments are possible future source-beds, and then, after having found them by means of a reconnaissance of certain critical areas of deposition of sediments, to choose the most likely regions for detailed studies. In the course of such a survey, information will be obtained as to the general distribution of organic matter in sediments and how the organic matter varies in different types of sediments.

In conducting such work it has been most important to find some suitable means of fairly rapidly determining the organic content of sediments. Distillations of dried sediment in the same manner that oil-shales are tested were found to be the most practical because, in addition to giving a good idea of the organic content they allow comparisons to be made with distillations of oil-shale and thus throw light on changes undergone in sediments from time of formation until the ultimate rock-product is reached.

Total ignition-tests were found to give, as a rule, a fairly good index of the organic content and hence to be a most important guide to the selection of samples to be distilled. Organic solvents, as tried out, yielded but little material. The ether-soluble portion of the alcohol-ether extract averaged only 0.06 per cent of the total sample and but slightly more than half this amount was fatty acid. Petroleum-ether, a good solvent for oils, yielded less than one-half the extract obtained by ether.

The reconnaissance of critical areas of deposition has but just begun and to date only two areas have been studied. One is the region about the Channel Islands west of Los Angeles and the other is Pamlico Sound, the large body of shallow, brackish water lying inside of Cape

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Hatteras. Distillations have been made only from the latter region. The study of other areas is rapidly being carried on at the present time.

The most important result of work on this problem, which is based on the distillation of some forty-five samples, is that all types of sediment, from clay to sand, upon distillation produced oil. The yield of oil was low and, in general, varied in amount with the degree of fineness of the sediments, ranging from a maximum of 2.7 gallons per ton in a clay-silt to almost nothing in a sand. This maximum yield of 2.7 gallons per ton is but five or ten per cent the amount obtained from the better grades of oil-shale which run from thirty to fifty or even more gallons per ton. It is perhaps surprising that 2.7 gallons per ton should be the highest yield secured, but the place of a higher production apparently was taken by a black flocculent precipitate that settled in the bottom of the distillate. The amount of this precipitate varied roughly with the organic content of the sediment and reached a maximum of fourteen gallons a ton. The temperature of formation of the oil ranged from 350° to 575° C, a range comparable to the production of oil from oil-shale. The temperature of initial oil-production varied widely in the different samples but in the sands was constantly 100° higher than the average for the clays and silts, which was 390° C.

Another interesting feature brought out in work on this project is that with very few exceptions the organic content of sediments increased as the sediment became more fine-grained. This inference is based on some seventeen samples collected from the Channel Islands region of southern California, and is supported by mechanical analyses made by the U. S. Bureau of Soils. The amount of organic nitrogen, fatty acid, and ignition-loss present in each sample was found, as a rule, to increase as the sediment became more fine-grained in character. The average organic nitrogen content was 0.2 per cent, fatty acid 0.04 per cent, and ignition-loss 10 per cent. Also, the amount of water held in its natural state in the sediment varied directly with the fineness of the sediment, ranging from 29 per cent in a sand to 66 per cent in a clay. The samples brought up from the lower parts of the deep depressions in the sea-floor in the Channel Islands region had the highest organic content of all the deposits collected in that area.

Two instruments to collect the sediments in sufficient quantities for distillation have been constructed. One is a modification of the Davis[1] peat-sampler. It consists of brass plunger that fits into a brass cylinder. The sampler by means of series of pipes coupled together is shoved in the mud with the plunger forced as far as it will go in the cylinder. At

[1] C. A. Davis, Mich. Geol. Survey, Ann. Rep., 1906, Part 2, p. 317, 1907.

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the depth at which the sample is to be taken the plunger is pulled upward until a spring-catch on the inside engages top of cylinder, which, due to the friction of the mud with the wall of the cylinder, does not rise with plunger. The whole apparatus is then forced into mud and the empty cylinder becomes filled with the sample and is hauled to the surface.

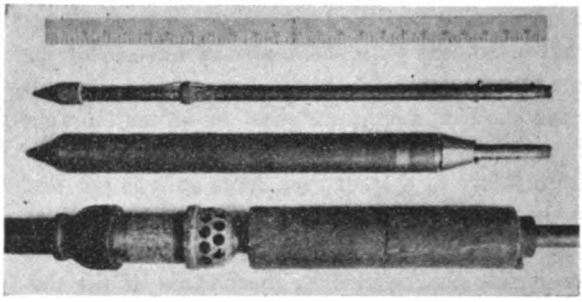

FIG. 1

Modified Davis peat-sampler (plunger with detachable top of collecting cylinder engaged in spring-catch at top and plunger inserted in cylinder preparatory to taking a sample at center) and modified Ekman sampler (with weights, perforated reducer, valve, and collecting tube at bottom).

The chief change made from the Davis sampler is that the plug that closes the top of the collecting cylinder is removable and is tapered conically upward so as to make easier the withdrawal of the instrument from the mud. This sampler will operate satisfactorily in water up to twenty-five feet in depth and will collect material, under favorable conditions, twenty-five or thirty feet deep in mud.

In deeper water the other sampler has to be used. It is constructed on the principles of the Ekman[2] and Albatross[3] samplers, but is much lighter, considerably cheaper, and much easier to transport and handle. However, it has the same disadvantage of those two samplers in that, as a rule, it will not take a sample more than four feet deep in the mud. The instrument consists of a four-foot collecting tube with beveled lower end, above which is a nipple that contains a butterfly-valve to permit water to flow through tube as the instrument sinks, but prevents the water from washing out the sample as it is raised to the surface. By means of a perforated reducer to allow the escape of water, the nipple is attached to a long stem of smaller pipe of sufficient length to insure center of gravity being below the middle of instrument. Lead-weights are fastened above perforated reducer to add momentum to sampler and to insure its falling vertically through the water. These may be re-

[2] V. W. EKMAN, Counseil Permanent International pour l'exploration de la mar. Publ. de circonstance, No. 257, 1905.

[3] F. B. SUMNER, et al., Univ. Calif. Publ. Zool., 14; (5) 1914.

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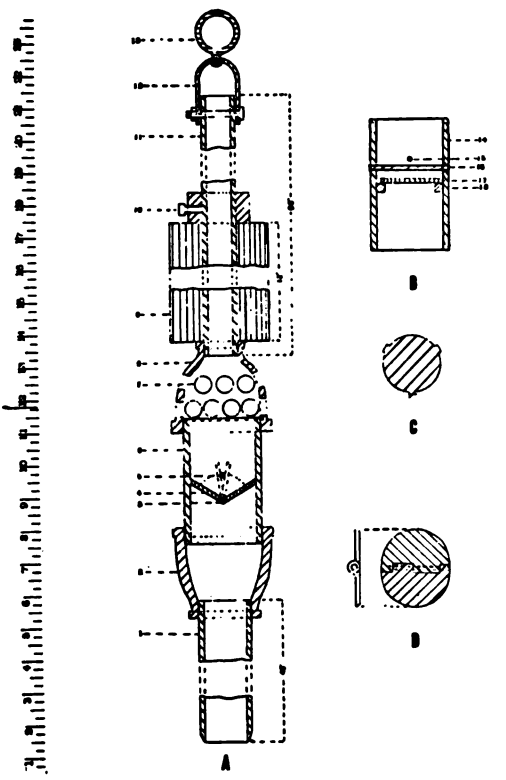

FIG. 2

Details of modified Ekman sampler: (*A*) diagrammatic cross-section, (*B*) alternative valve, (*C*) brass valve-plate, and (*D*) plan and elevation butterfly-valve. [(1) Collecting tube 1¼-inch iron pipe beveled to effect better penetration, (2) 1¼-inch by 2-inch reducer, (3) pivot-rod for butterfly-valve (4), (5) rod to prevent valve-wings passing mid-point of tube, (6) 2 by 4-inch nipple, (7) series of one-half-inch holes in 2 by ¾-inch reducer (8), (9) two 3 by 6-inch 15-pound lead-weights clamped by set-screw (10) on stem of instrument consisting of two four-foot lengths of extra-heavy ¾-inch pipe (11), (12) *U*-shaped shackle of flat iron, (13) swivel-joint attachment for rope or wire, (14) 2-inch nipple 4 inches long, (15, 16) brass rods at right-angles to each other to prevent flat circular valve-plate (17) being forced out of nipple (14), (18) supporting collar for valve-plate.]

moved when the sampler is operated by hand. Except for the simple butterfly-valve, all parts of the instrument can be purchased in a plumbing shop, and may be wrapped in a bundle four feet long and eight inches in diameter. A paper describing these instruments is in preparation.

In view of the magnitude of the task of making a reconnaissance of the organic content of a number of critical areas of deposition, practically all our attention has to be focused on that one phase of the problem and but very little time can be given to the numerous interesting and important problems that are continually presenting themselves, a few of which, however, are mentioned briefly.

The hydrogen-ion concentration of the muds of Pamlico Sound, as determined by Brom Thymol Blue, was found to vary but slightly throughout the Sound, ranging between 6.7 and 7.0. Furthermore, no material change was noted at depth in the samples even down to a depth of twenty-three feet.

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The reducing power of the muds as determined by the reduction of dyes was found to be but moderate, notwithstanding the presence of hydrogen sulphide, being about plus 0.2 volt compared to hydrogen.

The temperature-gradient of the muds as taken in Pamlico Sound in the latter part of January was found to be much lower in sands than in clays. In the but few samples taken deep in the mud, the depth at which a constant temperature was reached was between five and ten feet beneath the surface of the mud.

Water-soluble phosphate as determined on one sample taken from the Pacific Coast in 685 meters of water was 18.4 parts per million, nearly one hundred times the concentration in the lower sea-water.

In conclusion, the writer wishes to say that the results obtained on this project in a large degree have been made possible through the enthusiastic cooperation that has been received from all sources. Time does not permit the naming of the long list of cooperators, but Dr. Kellerman of the Bureau of Plant Industry, Drs. Burgess, Brown, and Washburn of the Bureau of Standards, Dr. Vaughan of Scripps Institution of Oceanography, and Drs. Alsberg and Swain of Stanford University, should be particularly mentioned for giving laboratory facilities that have materially aided the work.

Also, Messrs. O'Malley, Radcliffe, Higgins, and Goltsoff of the Bureau of Fisheries, Captain Parker of the Coast and Geodetic Survey, and Dr. Vaughan of Scripps Institution, have kindly granted the writer permission to accompany their boats so that samples could be collected, which, of course, is the most essential feature of the entire work.

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Washington, D. C.

THE CONFIGURATION OF THE BASIN OF THE PACIFIC

G. W. LITTLEHALES

The use of the sea, from early times, as the great highway of transportation and communication has made apparent to the United States the advantage of equipping its vessels with information respecting those waters through which their voyages might be directed, and for the fulfilment of this advantage a national institution, named The Hydrographic Office, has been established in the Navy Department. In relation to the Pacific Ocean, this institution produces and issues in successive editions about fifteen hundred different publications including charts ranging in continuous succession throughout its entire expanse.

The charts of fifty years ago, when deep-sea soundings began to be measured in the Pacific Ocean, were encumbered with symbols to repre-

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sent the many hundreds of reports of doubtful dangers that had come down from former generations of navigators.

To furnish evidence, by measuring the depth of the ocean, that would verify or disprove these reports, often doubtless based upon misleading appearance of the surface of the sea, was, to the United States Navy, a recognized obligation which resulted in this Service becoming the pioneer in furnishing authentic measurements of the depths of this great ocean, whose expanse exceeds, by ten million square miles, the total land-surface of the globe.

It was in 1873 that the U. S. S. *Tuscarora* ran the first trans-oceanic lines of soundings in the Pacific, in the course of which the Aleutian Deep was found and the great trough bordering Japan was discovered and named Tuscarora Deep. Soon afterwards the U. S. S. *Narragansett* sounded the route from Hawaii to Australia.

The charts of the Hydrographic Office have thus become, by natural development, the repository of the accumulated information with respect to the configuration of the oceanic basins, and in them may be found the facts of observation that lend themselves to the delineation of the isobathic contours.

Although there are regions of the Pacific where the number and distribution of the soundings are sufficient for a first approximation to the mapping of the conformation of the bottom of the ocean, as in the tract between California and Hawaii and other regions where an even greater degree of completeness has been reached, as in the case of the survey, in thirty-eight days, by the U. S. destroyers *Hull* and *Cory* of a tract of the bottom of the Pacific Ocean 34,000 square miles in extent, bordering the coast of California from San Francisco to San Diego and extending oceanward to a depth of 2,000 fathoms, yet, in general, it is not possible to draw the contours of the configuration, because, on account of the sparseness of the soundings, conjecture everywhere arises in attempting to do so, and there still remain great areas in this ocean that are entirely without soundings. In the North Pacific, there is a tract twice as large as the United States which has been crossed by only a single line of soundings spaced about two hundred and fifty miles apart, and in other parts of the Pacific basin there are areas as large as the continent of Australia in which not a single authentic sounding is recorded.

Besides giving the measurement of a depth, a sounding must be accompanied by two additional coordinates determining its position, since such a measurement applies only to one place on the globe; and, to be useful in defining configuration, a sounding must be attended with other soundings at intervals apart bearing a suitable relation to the dimen-

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sions of the orographical forms whose configuration is sought to be developed.

As a formative influence upon those engaged in measuring deep-sea soundings, the Hydrographic Office undertook an investigation to determine the form and dimensions of the slenderest formation, composed of the materials of the crust of the Earth, that could be raised from the depths of the ocean to a culmination in proximity to the surface, with sufficient crushing strength to remain standing under its own weight and the weight of the superincumbent body of water, on the principle that if the intervals between soundings were regulated to disclose the presence of the slenderest formation that could stand, then any orographical formation that might exist in Nature would be likely to be found. This investigation is published in the Proceedings of the First Pan-Pacific Science Congress held in Honolulu, in 1920.

The never failing stream of deep-sea soundings from national and institutional vessels of the countries bordering or having interests in the Pacific, among which those of the United States have maintained a leading part, is year by year advancing the once distant prospect of mapping the conformation and topography of the bottom of the Pacific Ocean to a nearer stage of feasibility, as when, in 1925, the United States Fleet, from the voyage to Australia and New Zealand, brought home about 6,000 soundings—many of them from regions unfathomed before that time.

And it is with satisfaction that attention may be turned to the unnumbered thousands of soundings on the continental shelf where the diligent labors of hydrographers have made the coastline of the world the best known of the world's major geographical features.

U. S. Hydrographic Office,
Navy Department,
Washington, D. C.

COMMITTEE ON THE OCEANOGRAPHY OF THE PACIFIC

T. Wayland Vaughan

ORIGIN AND PURPOSE OF THE PACIFIC SCIENCE ASSOCIATION

Since the Committee on the Oceanography of the Pacific is one of the committees established by the Pacific Science Association, it is pertinent to state briefly the origin and purpose of the Association. Scientific men have long recognized the need for the establishment of some kind of medium through which co-operative or co-ordinated effort in the investigation of the many scientific problems presented by the Pacific region might be effected. The preparation of programs of research began years ago,

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and more recently there have been special discussions of the problems of the Pacific at the meeting of the British Association for the Advancement of Science in Australia in 1914, before the annual meeting of our National Academy of Sciences in 1916, and at the Semi-Centenary of the University of California in 1918. Our National Academy and National Research Council appointed a Committee on Pacific Investigations and the activity of its members resulted in the First Pan-Pacific Science Congress in Honolulu in 1920. The Second Congress was held in Australia in 1923, and at the Third Congress, in Japan in 1926, definite organization of the Pacific Science Association was accomplished. Henceforth the Pacific Science Congresses will be held by the Pacific Science Association, which is primarily an association of the National Research Councils or equivalent bodies of the countries of the Pacific region.

Although scientific papers of the usual kind are presented at the Congresses, the primary purpose is to promote investigations, and especially those that require co-operative or co-ordinated effort. The usual procedure is to prepare summaries of available information on a subject, point out deficiencies in information, suggest programs of research to supply the deficiencies, and then to try to arrange for the execution of the programs.

Resolutions, drafted by those who have studied special subjects, are presented to the appropriate divisions or sections, and, if approved, are forwarded to the Council of the Congress, which endeavors to obviate duplication and to combine resolutions dealing with the same subject. Furthermore, an attempt is made to select only those resolutions which are harmoniously supported and behind which there is a group of members determined to make them effective. The selected resolutions are submitted to a general meeting of the Congress.

The purpose of the Association is the accomplishment of work. But it needs to be emphasized that the efforts are voluntary—no compulsion is possible. Furthermore, there are no formal agreements or contracts. Those interested do what they can, and already the accomplishments in several fields are large. For instance, very nearly everything called for in the resolutions adopted in Australia in 1923 has been done. It is hoped that the record for the effective execution of the resolutions adopted in Japan will be as good.

COMMITTEE ON THE PHYSICAL AND CHEMICAL OCEANOGRAPHY OF THE PACIFIC

In Australia in 1923 a resolution was adopted authorizing the establishment of a Committee on the Physical and Chemical Oceanography

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of the Pacific. Nine countries were represented on the committee, which was in large measure responsible for the excellent program of oceanographic papers at the Congress in Tokyo.

OCEANOGRAPHY AT THE THIRD PAN-PACIFIC SCIENCE CONGRESS

The Third Pan-Pacific Science Congress met in Tokyo between October 30 and November 11, 1926. There were excursions prior to, during, and subsequent to the meeting. The number of papers particularly devoted to oceanography was about thirty-five, but there were also papers on marine biology, fisheries, geologic features of ocean basins, and meteorology, that might appropriately have been given dual classification. The total number of papers of importance to oceanography was about seventy. Valuable oceanographic work is being done in Canada, Japan, the Philippines, the Netherlands East Indies, and Australia, as well as in the United States; and the Russians are resuming activities. The operations of Japan and of the United States are on rather larger scale than those of the other countries, but the intensive work in the Netherlands East Indies, and the proposed expedition in 1928 to the eastern part of the East Indian Archipelago, need to be borne in mind.

The Japanese are active in all lines of oceanographic research, except the calculation of oceanic circulation from physical data, but they are ready and have competent men for that kind of work. The outstanding institutions in Japan are the Hydrographic Department of the Imperial Navy, the Imperial Marine Meteorological Observatory at Kobe, and the Imperial Fisheries Institute; other institutions of smaller scale are conducting important researches. The activities embrace studies of the depths, currents, and tides of the sea, of the chemical properties of seawater, of marine meteorology, of marine bottom-deposits, of the quantity of plankton, of the life histories of commercial fishes, of marine mammals (especially the whales), of artificial cultures (such as culture pearls), and of fisheries technology. The intensive investigations of earthquakes by the Japanese are of value to oceanography, as well as to other branches of science.

ESTABLISHMENT OF THE COMMITTEE ON THE OCEANOGRAPHY OF THE PACIFIC

There were presented at the Congress in Tokyo several papers that dealt with international co-operation in oceanographic research in the Pacific. Among the papers was a general one by me, written in compliance with a request from the President of the Congress. Another general paper was entitled the "Pacific Ocean, Its Nature and Fauna," by P. J. Schmidt. There were several papers on more special subjects.

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My paper outlined a method of international co-operation based on each nation trying to work in that part of the Pacific adjacent to its own shores and by exchanging programs of research and information on the results of research with the other countries engaged in oceanographic investigations. It was obvious that the scope of the old Committee on the Physical and Chemical Oceanography of the Pacific was too narrow. It was decided, therefore, to disband that committee and to establish in its stead a new Committee on the Oceanography of the Pacific and to give its activities sufficiently broad scope for it to take in the special functions indicated by several excellent suggestions made by different members of the Congress. In the resolution establishing the Committee on the Oceanography of the Pacific, three subcommittees for each country were authorized, viz., subcommittees on physical and chemical oceanography on fundamental marine biology, and on fisheries technology.

The text of the first two paragraphs of Recommendation No. 5 reads as follows:

"Resolved—(1) That the surface-temperature readings from ships in the Pacific should have a time-frequency of at least once per hour to be adequate for oceanographic research; but as such frequency may not be practicable, the extensive installation of thermographs is recommended.

"(2) That the Committee on Oceanography endeavor to have issued a bulletin of actual surface-temperature readings, each bulletin covering a period of not longer than three months and appearing within about two months after the close of the period, if possible."

Before I left Tokyo, Dr. Sakurai, the President of the Congress, orally requested me to serve as Chairman of the International Committee, and later he corroborated his request in a letter. I accepted Dr. Sakurai's invitation with the feeling that I was undertaking a very heavy responsibility.

ORGANIZATION OF THE INTERNATIONAL COMMITTEE

As soon as possible after my return from Japan, I sent to the appropriate organization in each country represented in the Pacific Science Association a copy of the resolutions bearing on oceanography adopted in Tokyo and preliminary suggestions regarding the organization of the different National Committees and Subcommittees. The suggested procedure for the different countries reads as follows:

"The first step would be the appointment of the chairman of the National Committee and the chairman of the three National Subcommittees in each country represented on the International Committee. The chairmen of the National Subcommittees would organize their respective sub-

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committees. It may be desirable to have the same person serve on more than one subcommittee.

"Each subcommittee may be subdivided into sections if desirable, with a chief for each section. . . ."

Replies are now coming from the different countries.

ORGANIZATION OF THE NATIONAL COMMITTEE AND SUBCOMMITTEES FOR THE UNITED STATES

The first step in organizing the National Committee and Subcommittees for the United States was to submit the matter to our National Research Council and to seek advice or information from institutions and individuals. Letters have been received from the Hydrographic Office, Weather Bureau, Coast and Geodetic Survey, Bureau of Lighthouses, Bureau of Fisheries, Carnegie Institution of Washington, California Fish and Game Commission, numerous water, power, and light engineers, the members of the Advisory Board to the Director of the Scripps Institution, and many individuals, including some foreigners, whose opinions I desired. It is encouraging that virtually every one from whom a reply was expected has written. Many have gone to great trouble to supply detailed information that was needed in perfecting plans. I cannot here give the names of those who have helped, but I am profoundly grateful to them.

Regarding the proposed work in physical and chemical oceanography and in fundamental marine biology, the consensus of opinion is unanimously in favor of both; and doubt regarding the desirability of the proposed work in fisheries technology has come from only one organization. Our National Research Council has appointed me the Chairman of the National Committee for the United States; Dr. Geo. F. McEwen, of the Scripps Institution of Oceanography, has been appointed Chairman of the Subcommittee on Physical and Chemical Oceanography; and Professor L. B. Becking and Professor Laurence Irving, both of the Jacques Loeb Laboratory of Physiology, Stanford University, have been appointed respectively Chairman and Vice-Chairman of the Subcommittee on Fundamental Marine Biology. The composition of the subcommittees has not yet been decided, because it is a matter that requires careful consideration from the standpoints of both co-operating institutions and individual investigators engaged in the different kinds of research.

THE ROLE OF THE UNITED STATES IN THE OCEANOGRAPHY OF THE PACIFIC

Although knowledge of what is being done in other countries is needed by each country so that its program may be properly adjusted to the

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programs of other countries, each country must make and execute its own program. We are now, therefore, primarily concerned with what the United States may do, and we need to consider the activities of other countries only in so far as they bear on co-ordinate action in a general program.

On the basis of a real subdivision of oceanographic activities in the Pacific, previously indicated, it would be expected that the organizations in the United States engaged in oceanographic investigations would devote their efforts principally, but not exclusively, to the northeast Pacific. Where there are countries willing and prepared to do their share of oceanographic work, the principle of a real subdivision should be adopted, but for those segments of the Pacific adjacent to whose shores no countries are prepared to conduct oceanographic investigations, other provisions are necessary. Such is the case in South America. Therefore, it is incumbent on organizations in the United States, such as our Navy, the American Geographical Society, the American Museum of Natural History, the Carnegie Institution of Washington, and the Scripps Institution, to do what they can to add to knowledge of the eastern part of the southeast Pacific.

The work which may be done in connection with the three subcommittees will be briefly outlined.

PHYSICAL AND CHEMICAL OCEANOGRAPHY

Although they may be applicable to other fields of oceanography, the accumulation, classification, and interpretation of certain kinds of data are considered within the field of physical and chemical oceanography. These data are as follows:

(1) Depth of the sea, the configuration of the sea-bottom, and explanation of its features and of those of its margins; (2) marine bottom-deposits; (3) tides and waves; (4) the temperature and density of sea-water both at and below the surface; (5) the chemical properties of sea-water, such as *pH*, the substances in solution, for example, phosphate, silica, nitrogen compounds, and gases; (6) the interrelation between the physical and chemical features of the ocean and solar radiation; (7) the interrelation between the sea and the atmosphere; (8) oceanic circulation which includes all movements of the ocean-waters, except wave-motion, both at and below the surface, the causes that produce movement, and the methods whereby the rate and direction of movement may be determined.

For certain of the subjects enumerated provisions are already adequate. Among these are the tides, by the Coast and Geodetic Survey; and seis-

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mology, by the Coast and Geodetic Survey and the Carnegie Institution of Washington. The determination of the depths of the sea belongs logically to the Navy and to the Coast and Geodetic Survey. The rôle of such an institution as the Scripps Institution in a program for physical and chemical oceanography should be to try to help others in their investigations of such subjects as tides and earthquakes; its own field would comprise the determination of the physical and chemical properties of sea-water, the study of the interrelations between the physical and chemical features of the ocean and solar radiation, the study of the interrelations between the sea and the atmosphere, and the investigation of oceanic circulation by the use of current-meters and by applying the dynamical principles discovered and elaborated by Bjerknes, Ekman, McEwen, and others. The study of marine bottom-deposits, also, appropriately belongs within the sphere of such an institution.

Although an institution of the kind indicated can do much in its laboratories and by means of small craft and fixed collecting-stations and observation-stations, it needs aid in extending its range of collections and observations. The branches of our Government that operate fleets of vessels and commercial lines of vessels can render assistance of enormous value, and it is gratifying that they are now doing this. Only the necessity of being brief deters me from saying more regarding what the Navy, the Coast and Geodetic Survey, the Bureau of Lighthouses, and certain commercial lines of steamships have done and are doing. But it is possible for them to do more in making temperature-records, especially by installing thermographs on some vessels, and by collecting water-samples for both density-determinations and plankton-counts. Some vessels might make larger numbers of vertical sections of the water from the surface to the bottom and collect additional bottom-material.

The value of expeditions, such as that contemplated for the *Carnegie*, cannot be over-estimated.

One of the needs of both oceanography and meteorology is to have made available for use the large volumes of data on sea-surface temperatures and marine meteorology deposited in the Hydrographic Office and the Weather Bureau. The method of applying such data to the solution of problems in both physical oceanography and marine meteorology are now known, and it is earnestly hoped that provisions can be made for rendering the data available for use, as is being done by the Imperial Marine Meteorological Observatory at Kobe.

The present provisions in the United States for utilizing such data in the investigation of the physical oceanography and marine meteorology of the North Pacific, except in certain Governmental bureaus, consist of Dr. Geo. F. McEwen and Mr. S. W. Chambers, at the Scripps Institution,

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and Prof. C. F. Brooks and a part-time assistant at Clark University. An endeavor is now being made to increase the staff of the Scripps Institution by the addition of three scientific investigators and one clerk, and to procure funds for additional thermographs. If this endeavor should be successful, and if the data on marine temperature and on meteorological observations at sea filed with the Hydrographic Office and the Weather Bureau can be made available for use, great advance in both the physical oceanography and the marine meteorology of the North Pacific may be confidently expected within the following ten years. If this proposal were made effective, it and the work now being done by the Japanese, the Canadian Meteorological Service, and the Meteorological Bureau of the Netherlands East Indies, would be mutually complementary. For, please bear in mind, that if the plan proposed for the United States can be made effective we shall be engaged in a cooperative enterprise, which at present includes at least three Pacific countries besides the United States.

FUNDAMENTAL MARINE BIOLOGY

This subject depends on the investigations in physical and chemical oceanography for data on environment. It deals primarily with the interrelation between the organisms and their environment and with the interrelations between the organisms themselves. Therefore, biophysics, biochemistry, physiology, food-chains, and life histories are all subjects fundamental and all subjects to which far too little attention has been paid. To this field should be referred investigations of photosynthesis, bacteriology, and skeleton formation, quantitative studies of plankton and the physiology and ecology of plankton organisms, the food-value of plankton and its consumption by other organisms, the food of the higher organisms, their physiological responses and the causes of migrations, the life histories of organisms, including studies of pelagic fish-eggs and larval fishes, and many other problems.

The continuing investigations must be conducted mostly at established laboratories such as the Friday Harbor Laboratory of the University of Washington, the Hopkins Marine Laboratory and the Jacques Loeb Laboratory of Stanford University, the Laboratory of the California Fish and Game Commission at San Pedro, the Scripps Institution of Oceanography at La Jolla, and the Marine Biological Laboratory at Honolulu. But more than mere laboratory work and near-shore expeditions are needed. The contributions that can be made by such expeditions as that projected for the *Carnegie* are of great and profound importance. Recurrent expeditions of magnitude are needed.

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It is possible for the Governmental institutions that operate sea-going vessels to help in the investigations by collecting, while on their voyages, water-samples for plankton-counts, as well as by obtaining other data and collections already indicated. If the different possible agencies could undertake to procure additional collections of material and data they would increase their valuable aid in advancing knowledge of the biology of the sea.

FISHERIES TECHNOLOGY

The name of one of the subcommittees of each national committee on the oceanography of the Pacific is "Subcommittee on Fisheries Technology." It would have been better to have omitted the word "technology" thereby leaving the subcommittee free to consider any fisheries problem deemed desirable.

The fisheries industry should rest on a foundation of researches in physical and chemical oceanography and fundamental marine biology, for from these researches will be derived knowledge of the conditions that control the spawning and hatching of eggs, the success or failure of a hatch, and the distribution and supply of adults. Actually, fisheries problems cannot be sharply delimited from the general problems of oceanography; and it must be recognized that the needs of the fisheries industry have led to oceanographic researches of the most profound significance, for instance, many of the investigations of oceanic circulation.

The problem of the possible depletion of resources and the steps needed to preserve supplies of useful aquatic animals and plants present themselves.

The study of the technology of the fisheries industry should begin with the supply and should cover methods of fishing or harvesting, preparation and preservation of the catch or harvest, the food-value of fish, and marketing. The utilization of the parts of fisheries products not suitable for food should receive investigation for the obvious reason that any additional revenue derived from such a source will strengthen the industry.

The hope was expressed by the Congress that this subcommittee would be gradually developed so that it may function as a clearing house for information on fisheries technology for all the countries of the Pacific. In each country the work of this subcommittee should be in association with the fisheries societies.

There are at present, so far as I have ascertained, only two institutions on the Pacific Coast of the United States actually engaged in researches on fisheries technology, viz., the College of Fisheries of the University of Washington and the California Fish and Game Commission, but in-

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vestigations of significance to the fisheries industry are being conducted at the Jacques Loeb Laboratory at Stanford, at the Scripps Institution, and at other places. It appears probable that there may be worked out between several institutions a program which will yield results of value, but no definite steps have yet been taken. Suggestions have also been received for the collection and distribution of information.

Although the Subcommittee on Fisheries Technology has not yet been organized, enough suggestions have been received to warrant belief that it can be organized and can be made to render valuable service.

A JOURNAL OF OCEANOGRAPHY

There is at present no regular journal of oceanography published in an English-speaking country. There is need for a journal in which both original articles and abstracts may be published. This matter might be taken up by the Geophysical Union and the other appropriate divisions of our National Research Council.

CONCLUSION

On the Pacific Coast of the United States and in the Hawaiian Islands there are at least seven institutions or laboratories engaged in oceanographic work of some kind. These institutions or laboratories are gradually getting together and before long concerted action may be expected. But only the Scripps Institution is working on physical oceanography and marine meteorology.

The valuable contributions that may be made by such institutions as the Carnegie Institution of Washington, the American Geographical Society, and the American Museum of Natural History have been indicated.

Our Navy might increase the valuable aid it is already rendering by supplying more data on sea-surface temperatures and marine meteorology and by the collection of surface water-samples for salinity-determinations and plankton-counts.

The Coast and Geodetic Survey might add to its present valuable assistance by the installation of thermographs on its vessels and by making a larger number of vertical sections of sea-water.

The Bureau of Lighthouses might add to the help it is now giving by arranging for the lighthouse-tenders to do oceanographic work while on their cruises.

The United States Shipping Board should be invited to assist in this enterprise.

A great service that can be rendered by the Hydrographic Office and the Weather Bureau is to make available for others the use of the sea-

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surface temperature records and the data on marine meteorology deposited in their archives.

Our National Research Council can help in the preliminary steps toward establishing a Journal of Oceanography and perhaps it can assist in procuring funds for traveling, office, and publication expenses.

This evening there are assembled with the members of the Section of Oceanography, representatives, in most instances the heads, of those governmental bureaus and of the private scientific institutions most concerned with oceanographic research in the Pacific. I trust that every one here will join with all the others and do whatever he can, as an individual or as the head of a bureau or institution, toward enabling the United States to make contributions to knowledge of the oceanography of the Pacific Ocean commensurate with its strength and standing among the nations of the world.

Scripps Institution of Oceanography,
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THE COAST AND GEODETIC SURVEY AND OCEANOGRAPHY IN THE PACIFIC

N. H. Heck[1]

One of the resolutions passed by the Third Pan-Pacific Science Congress at its recent meeting in Tokyo emphasized the need for more knowledge of bottom-configuration in the Pacific region, especially in the vicinity of the island groups. In my opinion, there should have been added the areas adjacent to the coasts because these two classes of area include most of the interesting features of the region.

Even when the vast area of the Pacific Ocean is taken into account, it is found that the Coast and Geodetic Survey is charged with the survey of a not inconsiderable part of such area in the North Pacific. Its normal activities include surveys from the coast or from island groups to a limit usually fixed at the thousand-fathom-curve. Such surveys include the area from the Mexican boundary to the Canadian boundary and from Dixon Entrance to Attu Island, the westernmost island of the Aleutian group, a distance of 3,500 miles; along the western coast of Alaska north of the Aleutian group 1,200 miles; the entire Hawaiian group extending 1,400 miles, and the entire Philippine group, length north to south 1,200 miles and east to west 150 to 650 miles.

[1] Representing Colonel E. Lester Jones, Director, U. S. Coast and Geodetic Survey.

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In addition to this normal work, a number of vessels passing between the Atlantic and Pacific coasts of the United States have taken soundings and other observations en route from the Panama Canal to California, and the same practice has been followed between California and the Hawaiian Islands, and between the State of Washington and Alaska.

These surveys include soundings by wire and echo-methods, the obtaining of temperatures and water-samples for the determination of salinity at the surface and at various depths and of bottom-samples. Special oceanographic work has been done also for the Scripps Institution at La Jolla, California.

Some very interesting submarine features have been developed as the result of these surveys, especially a series of deep troughs extending parallel to the coasts of Mexico and Central America and the great submarine valley which approaches the California coast in Monterey Bay.

In connection with the execution of this work, the Coast and Geodetic Survey has taken an important part in the development of new methods. In connection with the echo-soundings it was the first to apply proper velocities of sound based on temperature, salinity, and pressure to soundings of all depths. Two of its officers prepared suitable tables for readily determining these velocities and later presented for the Pacific Ocean a method of applying velocity-corrections which requires knowledge only of the latitude and approximate depth of the soundings. It has applied the fathometer of the Submarine Signal Corporation of Boston, which was developed primarily for navigation, to hydrography and has developed a number of improvements which make it more suitable for such use.

The radio acoustic method of determination of position insures greater accuracy in the surveys of the critical area lying between the coast and the thousand-fathom-curve, especially in regions where frequent fogs or low-lying shores prevent objects on shore from being seen at considerable distances. The possibility of working a larger part of the time is resulting in a considerable increase of output.

The fact that the Coast and Geodetic Survey has taken up these new methods and made them effective shows its attitude in this matter and it is scarcely necessary to say that it is ready to adopt other new methods for carrying out the various operations that come directly within the field of its work, or which aid oceanography in general, provided it is not required to go outside of its field or interfere with its regular work.

It scarcely needs to be said that the Coast and Geodetic Survey is interested in the extension of oceanographic work in the Pacific Ocean. It not only appreciates the needs but the difficulties and it clearly under-

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stands that no one nation can or should undertake this great task alone. An organization under which all the nations bordering the Pacific can exchange views and discuss plans should at the very least provide for the first steps which must be taken, and it can be expected to accomplish much more.

A matter of primary oceanographic importance is the determination of accurate datum-planes. These serve as the basic reference planes from which depths in the ocean are measured and thus permit the detection of changes in the relative elevation of land to sea. The Coast and Geodetic Survey has determined such planes at a number of points on the Pacific Coast of the United States and is now maintaining in operation continuously five primary tide-stations on that coast.

The circulation of the sea near the land and the relation of this to the wind has been studied by the Coast and Geodetic Survey for several years, by means of observations on the five light-vessels stationed along the Pacific coast. The data derived establish definite results for winds of various directions and velocities.

The extension of work of this character to the entire Pacific region would not only add greatly to the value of the information that has been obtained, but would also be of international benefit.

The use of such work to oceanographers is obvious, but the Coast and Geodetic Survey is especially interested in another application. The Survey is constantly called upon to locate earthquake epicenters in the Pacific because the great earthquakes frequently occurring there are recorded on its instruments. It is important to know whether a special bottom-formation is associated with a submarine earthquake, and since the deep ocean-troughs stand first among such formations, it is at present a great handicap that we scarcely know their limits. Past work of the Coast and Geodetic Survey in the great deep north of Porto Rico shows that the ocean-deeps can be sounded to their greatest depths by the echo-method.

There is also need for the extension to the entire Pacific of the ocean gravity-surveys which have been conducted so successfully by Dr. Meinesz. This work is especially needed in the Pacific since the surface-layer of the Earth beneath this ocean appears from various evidence to differ from that elsewhere in the Earth so that the determination of all the facts by the combined efforts of oceanography, seismology, and geodesy is of the greatest importance.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTION OF VOLCANOLOGY

(Washington, D. C., April 28, 1927)

THE WORK OF THE GEOPHYSICAL LABORATORY ON HOT SPRINGS

E. T. ALLEN

Inception of the work. My active interest in the study of volcanic phenomena began in 1916 when I accompanied Dr. A. L. Day to the Lassen Park with the purpose of studying the hot springs in that locality. The earlier work was concerned with general observations on such matter as topography, temperature, and drainage, and with the processes of rock decomposition. It led to the discovery of a simple relation between the acid and the alkaline springs. Both are regarded as derived from the same source by the same general process of rock decomposition. The majority of these springs contain sulphuric acid together with what are plainly the products of its chemical action on the surrounding rocks, namely, the sulphates of the rock bases dissolved in the water, and silica and kaolin precipitated in it. Now, if the acid continues to react with the rock, obviously it is merely a matter of time, or of the existence of some other favorable condition, until the acid will be completely neutralized. When that point has been reached further rock decomposition by the agency of hot water and carbonic acid, which is everywhere escaping from the springs, will bring into solution carbonates, bicarbonates, or both, which impart to the water an alkaline character. The alkaline springs, therefore, are seen to be logically subsequent to the acid springs.

It was not until the Katmai region, Alaska, had been visited, and the importance of the relation of hot springs to fumaroles had been realized, that it was found possible to formulate a satisfactory theory of the cause and origin of hot springs. In its simplest terms the theory states that hot springs are fed chiefly by ground-water heated by magmatic steam. Two points in it may be stressed: the simple and rational mode of heat transfer, and the effectiveness of the agency where the heat is derived mostly from the condensation of the steam. The theory is based not only upon the close association of fumaroles and hot springs as well as upon other significant field observations, but also upon a knowledge of the composition of rocks and their behavior on heating. All types of igneous rocks, when heated to a sufficiently high temperature, give off a mixture of volcanic gases of which steam is always the preponderant constituent. The escape of such gases as are found generally in hot-spring regions is therefore a necessity, provided only that there is a body of hot rock below ground and that the gases can find access to the surface.

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Cracks in the rock would of course offer the natural outlet. This is doubtless the significance of the faults which in so many cases, both in the Lassen Park and elsewhere, have already been noticed in close association with hot springs.

Phenomena at The Geysers, California. Quite different from the hot ground of the Lassen Park in its superficial features is a small area in the Coast Range of California known as The Geysers. The hot springs here are very small, the fumaroles feeble, and the exposed rocks decidedly different in nature; but in essential characteristics a marked resemblance exists between the two districts.

It was found possible at The Geysers to measure the discharge of a comparatively large group of springs, and when the measurement was repeated from time to time as the hot, dry summer advanced, the discharge was seen to fall off continuously—an effect which would have been unintelligible unless a part of the water-supply came from the surface. In the Lassen Park, seasonal changes in the temperature of the springs were observed and variations in water-level or in the volume of discharge were easily recognizable; but at The Geysers changes of this kind were not easy to follow. It was only after actual measurements had been made that all doubt in the matter was dispelled.

By far the most remarkable feature at The Geysers is the small group of steam wells developed for industrial purposes during the last few years. The thermal energy originally manifested at the surface of the ground was quite feeble, but a powerful flow of steam is developed by drilling, generally within the first hundred feet, and in the finished wells, which vary in depth from 200 to 650 feet (60 to 200 meters) pressures range from 60 to over 275 pounds per square inch (4.2 to 19.4 kg. per sq. cm). When the wells are opened enormous amounts of steam escape. When they are closed again, even after months of discharge, the pressure returns again to its former magnitude irrespective of the season. Temperatures at the top of the closed wells reach a maximum of 190° C and in one of them at a depth of 250 feet (76 meters) a temperature hot enough to melt tin (232° C) was found.

Numerous tests disclosed the presence of other volcanic gases with the steam in all the wells, and a series of temperature and pressure measurements proved that the steam was superheated. That such huge quantities of steam (a maximum of 52,000 pounds or 23.6 metric tons of steam per hour) escaping from semi-arid ground with a poor capacity for the conservation of the water-supply, could be derived directly from surface water, seemed highly questionable from the first; and when its superheated character and its constant association with other volcanic gases were discovered the view was rejected as untenable. On the other

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hand, steam escaping from a magmatic solution would necessarily show a drop in pressure below that of steam escaping from a body of water at the same temperature; in other words it would be superheated. Again, the apparently unlimited store of the steam as well as all its other characteristics is in harmony with the view that it originates in a great magmatic reservoir.[1]

Investigations in the Yellowstone Park. The importance of magmatic steam as facilitating the explanation of geyser action is so obvious that when observations were extended to the Yellowstone Park one of our first concerns was the search for superheated steam vents. Notwithstanding the relatively large supply of ground-water here, superheated steam was found escaping from vents in five different localities in the Park. The maximum temperature found was 138° C, where water boils at a temperature of 92° to 93° C.

Superheated steam was found also in the Lassen Park in one locality. It occurs in many of the Katmai vents and finally in the Tuscan steam wells, as measurements have proved. Superheated steam in volcanic areas is thus by no means a sporadic occurrence. Drilling and casing would probably reveal its presence not far below ground in many other places but we already have observations enough, it seems to me, to afford a thoroughly sound basis for the theory of heat transfer which has been expressed here.

When we compare the springs of the three localities under discussion, we find all to be conditioned as to size and concentration by climate and topography. In the Coast Range of California where the climate is semi-arid and the water-supply poorly conserved, the smallest and most concentrated springs occur; and in the Yellowstone Park where the drainage basins are the largest and the water-supply best conserved, the springs are much the largest and deepest and the waters quite dilute. This statement is an obvious acknowledgment of the influence of surface water on all the springs.

In all three localities the chemical nature of the rocks is clearly reflected in the mineral waters which issue from them. The springs of the Yellowstone Park which issue from rhyolite are highest in the alkalies, and calcium and magnesium drop to a very low figure. In the springs of the Lassen Park which issue in dacite, the alkalies and alkaline earths approach the same order of magnitude. The aluminum derived from the rocks of both localities is generally found precipitated in the sediments in the form of kaolin or alunite. The springs of the

[1] The primary mass of steam is regarded as magmatic; a subsidiary portion may very well be taken up on its way to the surface.

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Coast Range which are closely associated with serpentine are highest in magnesium and lowest in the alkalies, which almost vanish in most of them. It may be noted that these facts are in harmony with the view that the spring-waters derive their mineral content from slight depths, although, of course, they do not prove it since the surface rocks may be of very considerable thickness.

A detailed chemical survey of the Norris Basin in the Yellowstone Park indicates that the acid and alkaline springs there are similar in derivation and in mutual relationship to those of the other two localities. In all three of them the condition generally most favorable to the formation of an alkaline water seems to be a concentration of acid so low that it quickly becomes neutralized in the water that feeds the spring, for in the majority of cases the concentration of the SO_4 radical in the alkaline waters is of a lower order of magnitude than it is in the acid springs.

Among the new problems that present themselves in the Yellowstone Park is a more complete and satisfactory explanation of geyser mechanism. Bunsen discovered the condition of first importance when instead of thermal equilibrium in the geyser tubes he found hotter temperatures at the bottom; but much more work will probably have to be done before the great diversity of behavior in different geysers can be reasonably explained. Fortunately we now have a number of facts which have an obvious bearing on the problem but which have not yet been applied to it.

The waters of the Norris Basin contain several elements in amounts which can be explained only by assuming some kind of concentration intermediate between the decomposition of the rock and the solution of the products. Thus arsenic occurs in concentrations far greater than it does in igneous rocks, so great that its deposition in the form of sulphides is in progress in many places. Unlike the waters of the Lassen Park and The Geysers, those of the Norris Basin contain chlorine (as chlorides) often in relatively large amounts, but even here the distribution is very unequal; some springs contain practically none. This recalls the old problem of the high concentration of chlorine in sea-water. Whether the two cases are comparable is open to question. Problems of the same kind occur in other places, but so far as I know they have never been satisfactorily handled.

The place of hot springs in the system of volcanism. Hot springs are commonly regarded as the last *temperature*-phase of volcanism. This view is perfectly rational. At the same time another factor is equally vital—the *activity of the volcanic gases.* All phases of volcanism are related to one another through their connection with the volcanic gases. It is the expansive force of the hot gases which conditions the rise of

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lava in craters and which supplies the energy for the major volcanic eruptions. It is the combustion of inflammable gases which prolongs the life of the lava flows. In a less intensive stage of volcanism the gases escaping through vents in the ground constitute the fumaroles and when the fall of temperature permits the percolation of ground-water it is still the volcanic gases which supply the heat of hot springs. Finally, it is steam and its chemically active associates, hydrogen sulphide and carbon dioxide, which cause the decomposition of rocks, the separation of silica, the formation of salts, mineral waters, and other secondary products which form such striking features of the volcanic landscape. The volcanic gases are thus not only the constant associates of every phases of volcanism, but together with the heat they are the active agency in them all. Because the gases are not so easily handled and tested as rocks, and because they form an insignificant portion of the rocks by weight, geologists generally have not yet realized their importance and what the volcanic processes would be without them.

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THE PRESENT STATUS OF THE VOLCANO-GAS PROBLEM

E. S. SHEPHERD

Prior to 1911 my notions of volcanoes were determined by textbook diagrams, fire insurance calendars, and the conventional Neapolitan postcards. In that year I visited Kilauea under the guidance of F. A. Perret, and found some revision of my ideas necessary. I am still revising them. At that time, and during my stay, Kilauea was entirely normal; that is, there was a circular pool of lava about a hundred meters in diameter some thirty meters below the rim of Halemaumau. Nothing happened except an occasional rise of a few meters with overflow, or drop of a few meters with some falling in of the lake wall. Otherwise the lake bubbled away with quite regular fountaining, flow, and hissing cracks. Since it was generally accepted that beneath the lake there was an unimpeded conduit leading down to a convenient magma chamber, and also that the lake had no outlet, a chemist would instinctively deduce that the energy supply must come from the gases, since these were the only products evolved. In 1912 I accompanied Dr. A. L. Day on another expedition, with the object of collecting some of these gases and determining their composition. The results of that expedition are familiar to you.

Since then, collections have been made both by ourselves and by Professor Jaggar, to whom we owe the best collection of volcano-gases ever

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secured. As a result, we have analyses of some twenty-four vacuum-tube specimens taken at various times and from various promising sources over a period of seven years. These data have been published with little or no comment in the Bulletin of the Hawaiian Volcano Observatory.[1]

Meanwhile we turned our attention to the gases which still remained in solution in the cooled lava, thinking that, special solubilities aside, we might find further clues as to the possible energy supply. It develops that the volatiles which can be pumped out of the lava when it is heated in vacuo are practically identical with those collected from the lake itself. The agreement is much better than we had any reason to expect.

We then extended our experiments to volcanoes of different type, such as Lassen Peak and Mt. Pelée. Here, unfortunately, we cannot compare the lava gases with those erupted; but our Hawaiian results as well as general theory incline us to believe that the differences will not be great.

Regardless of origin, the volatiles which can be obtained from lavas seem to agree upon one thing, and that is that the water-content shall be about 80 per cent of the total. There are exceptions, of course; but for active lava the figure seems quite general. Whether this water is magmatic or whether it is to be derived from deep-seated combustion of primitive hydrogen, or perhaps has been absorbed by the magma on its way to the Earth's surface, must remain for the present a matter of personal opinion. It is difficult for a chemist to imagine a gas leaving the depths and finding its way to the surface without being contaminated by the volatiles resident in the various rocks and strata through which it must pass. In fact such a passage resembles an absorption-tower of greater or less efficiency so that any discussion as to whether these gases are really magmatic or not has very little objective foundation. Of course, if one believes in unimpeded straight conduits leading directly down into the magma chamber, with a rapid rise of magma through such a conduit to the surface, the probability of the gas being magmatic is considerably increased. Such an assumption seems hardly warranted. At Kilauea it ought to be fairly clear by this time that while there is a more or less well-defined central vent, the "unimpeded conduit" turns out to be, at least in its upper portion, a breccia through which the lava must froth its way to the surface. At the andesitic volcanoes the conduit seems equally ill-defined, though for a different reason. Probably the mechanism of eruption is entirely different, being in these cases the result of a crystallizing mass, as at Mt. Pelée and Lassen Peak.

[1] Bull. Haw. Volc. Obs., 7: 94-97 (1919); 8: 65-67 (1920); 9: 83-88 (1921).

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Of the other gases present we note that hydrogen and carbon monoxide are present in very small amounts. In other words the chemical energy of these gases seems to have pretty well exhausted itself before they reached the surface.

Sulfur and the halogens are usually considered as of more interest in connection with fumaroles and chemical alteration than as sources of heat, while the rare gases are present in discouragingly small amounts.

In his paper on the chemistry of volcanism,[2] Allen examined the reactions usually invoked to supply volcanic heat and dismissed them as insufficient. They can furnish heat but the quantities of gas required become rather incredible. The oxidation and reduction reactions can probably be dismissed as of only local import and that a minor one. It may be noted in passing that the classic equation between ferrous oxide and water may be permanently retired, since we are dealing not with ferrous oxide but with ferrous silicate, in which case the sign of the heat change is just the opposite. The chief failure of these combustions lies rather in the means of getting an adequate supply of oxygen.

On a former occasion I called your attention to the chemical results of such engulfments as Professor Jaggar had demonstrated in the recent great subsidence at Kilauea, and pointed out that in this way large quantities of oxygen could be fixed by the iron silicates and buried in the heart of the mountain. The actual amount of heat which can be obtained in this way is, I find, too small to be significant in the general reactions of the volcano, though it adds appreciably to the heating up of the volcano edifice. As a general mechanism we may say that the fixation of oxygen by iron silicates will not suffice, since with the Kilauea basalt we find that with all of the available iron oxidized and then reduced again to ferrous silicate the iron oxides in a unit of lava would generate only enough heat to warm that unit some eight degrees Centigrade, and that with the lesser iron-content of more acid lavas it becomes negligible. Furthermore, to be of any service in volcanism proper it would be necessary to devise some mechanism for repeatedly oxidizing the iron, and this involves the same fatal defect of all the oxidation reactions—the introduction of large quantities of oxygen into the lava. As I see it, Professor Jaggar's surface oxidation hypothesis, although based upon good observation, is negatived by the fact that the ratio of nitrogen to water actually found in the gases is about sixty-eight parts of water to eight of nitrogen, whereas there should be seventy parts of nitrogen to thirty parts of water if the oxygen was derived from the

[2] Journ. Franklin Inst., 193: 29-80 (1922).

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air. It is difficult to imagine oxygen diffusing into the lava column and leaving the nitrogen behind.

Nearly all of the suggested reactions involve moving large quantities of gas through the lava at a considerable rate of speed if the four hundred million calories per second are to be supplied—this figure being that estimated by Daly from his measurement of the heat-radiation of the lake. Diffusion seems much too slow to move the amounts of gas required, and a little simple arithmetic readily shows vesiculation at any great depth, or the movement of vesiculated material, to be improbable.

It was probably some such considerations as these which caused Day to suggest that the shifting of chemical equilibrium with changing temperature and pressure in the lava might furnish some portion of the heat necessary for the observed phenomena. This hypothesis has one great advantage in that the heat is generated, so to speak, *in situ* and requires no gross movement of the gases within the magma. Of the suggested reactions, that between sulfur and carbon dioxide could furnish the most heat, and if the total heat of this reaction could be transported and transformed in this way the reaction could supply the necessary heat for a hundred-meter lake without an incredible rate of gas evolution at the lake surface. In this connection it is interesting to find that the final state of this reaction calls for a ratio of sulfur to carbon dioxide which is sensibly identical with this ratio as determined from the average composition of all of our vacuum-tube samples. It does not follow that this reaction furnished all of the heat at Kilauea, but it does imply that this reaction is the dominant one. It is important to note that this ratio does not hold for the andesitic volcanoes, Lassen Peak and Mt. Pelée, if we may judge from the gases still retained in solution in the chilled glassy lavas.

At present I believe that the necessary heat for maintaining the lava lake at Kilauea could be obtained by gas heating without too incredible amounts of gas, but feel that such an hypothesis is unnecessary. The same amount of heat could be easily supplied by the rise of a few cubic meters of lava a second with only a two-hundred-degree drop in temperature. It will be recalled that the gas-heating and gas-fluxing hypotheses were invented primarily to account for the lava lake on the explicit assumption that it was an undrained lake, a closed system.

If, on the other hand, we make the entirely probable assumption that Kilauea is merely a lava spring with not one but many irregular subterranean outlets, these hypotheses are less necessary. However improbable such a conception may appear to those familiar only with the continental mountains, a short examination of the porous structure of the Hawaiian range and the history of the various flows and eruptions on the active

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island will show that no absurdity is involved, rather the contrary. A more detailed explanation of this revived hypothesis will be presented in a forthcoming paper on the Hawaiian volcanoes. Meanwhile I would suggest that a plausible case can be presented for believing that volcanoes are developed, not from some one magma chamber, but from numerous roots, which, in the case of the basaltic volcanoes, go to considerable depths; that they are the fundamental volcanoes, and that among the more superficial roots of the basaltic volcanoes the acid volcanoes take their origin. If this prove to be feasible, then we can withdraw the gas-heating and gas-fluxing hypotheses from their present sadly strained position and apply them readily to those superficial, though highly spectacular and even terrifying, phenomena which a chemist more or less unconsciously comes to regard as the quintessence of volcanism.

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THE CONCENTRATION OF METALLIC CONSTITUENTS BY VOLCANIC EMANATIONS

E. G. Zies

This paper discusses the concentration of metallic constituents by means of the vapor-phase activity of an igneous body. Many geologists and geochemists have considered the possibility of such concentration; and its probability became apparent after studying the incrustations found in the volcanic area of Alaska known as the Valley of Ten Thousand Smokes. In this Valley, approximately a cubic mile of a rhyolitic pumice was deposited after having been blown through the old floor of the Valley. Many fumaroles are located in the pumiceous area. The persistence of relatively high temperatures (97° to 650°) and great volumes of steam since the eruption in 1912 indicate that the emanations derive their heat from a fairly deep-seated igneous body.

The emanations contain over 99 per cent of steam, together with approximately 0.12 per cent HCl, 0.03 per cent HF, and 0.03 per cent H_2S. These acid gases have greatly altered the pumice in the vicinity of the vents of the fumaroles. The metallic constituents *Ag, Pb, Cu, Sn, Mo,* and *Zn* were found in nearly all of the incrustations so far examined. Especially noteworthy is the concentration of molybdenum as "molybdenum blue" in several large fumarolic areas.

Analysis of the pumice of the Valley and analysis of the rhyolitic glass obtained from a new volcano in the Valley revealed the presence

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of the metallic constituents mentioned above. This fact together with the extensive alteration of the pumice by the acid gases indicates strongly that the *Mo, Cu,* etc., in the "molybdenum blue" areas were obtained from the pumice itself.

Concentration has taken place, however, by still another method. Magnetite (Fe_3O_4) was found in 1919 in a number of fissures. It was deposited in large masses as loosely coherent octahedra against the roofs of the fissures. A simple calculation based on the iron-content of the pumice and the approximate extent of the magnetite-deposit showed that the entire cubic mile of pumice would have been required to furnish the iron for magnetite in one fumarole area. Obviously this is out of the question. It is believed that the magnetite was derived from some combination of iron and halogen that had been brought up from below in a vapor-phase. All of the metallic constituents mentioned above were also found in the magnetite.

Thallium, gallium, arsenic, antimony, bismuth, and cadmium were likewise found in many of the incrustations. The amounts were quite small (0.002 per cent and less) but could readily be determined by a carefully controlled chemical and spectrographic technique.

All of the metallic constituents mentioned have the following property in common—either their halides or oxides have appreciable vapor-pressures at the higher temperatures found in the Valley. The amount of material that can be brought up from below by such a mechanism will depend on the partial pressure of the acid gases, on the vapor-pressure of the metallic halide or oxide, on the ease with which hydrolysis will take place, and finally on the velocity with which the steam is moving. It is believed that the steam at the more elevated temperatures plays an important rôle in sweeping out the reaction products formed below.

As the temperature of escaping steam falls, important changes are likely to take place both in the metallic constituents formed from the decomposition of the pumice by the acid vapors and in those brought up by the acid vapors. One illustration will suffice. On a subsequent expedition in 1923, Dr. C. N. Fenner had no difficulty in determining the location of the fumarole area from which the magnetite was obtained. He did not, however, find any magnetite but found instead a siliceous material impregnated with crystals of sphalerite and galena. He also noted that the temperature of the steam had fallen to 97°. As the temperature falls water will condense near the orifice and provide an acid environment in which the magnetite is no longer stable, but the lead and zinc in the presence of H_2S will be stable as sulfides, provided the acid concentration is not too high.

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Differential concentration can be brought about by virtue of the fact that some of the halides are more readily hydrolyzed than others. Thus steam and hydrochloric acid passing over a body containing Fe_2O_3 and TiO_2 will remove both iron and titanium; but since the titanium chloride is more readily hydrolyzed than the iron chloride, the titanium will not travel as far as the iron.

It is quite probable, therefore, that in a volcanic area such as the Valley of Ten Thousand Smokes, or even in the more deep-seated hearth of a volcano which is gradually becoming quiescent, concentration of metallic constituents will take place provided, of course, that the igneous body or adjacent material contains such constituents. The prime requisites are differences in temperature and pressure.

Such concentration is to be looked upon as the preliminary concentration, since lowering of temperature will eventually permit water to be present and this together with the acids (HCl, HF, H_2SO_4) will, as we have seen in the case of magnetite, produce a new set of conditions under which a new set of minerals will be formed. In this new set of minerals the metallic constituents can be concentrated to a still greater degree.

No extensive ore body is likely to be formed in the Valley of Ten Thousand Smokes on account of the great porosity of the pumiceous deposit. This great porosity permits free access of surface water which can carry the acid waters together with the metallic constituents into the drainage system of the area. A volcanic hearth, on the other hand, would prove a much more favorable locality.

Even if the igneous mass is deep-seated, the activity associated with the vapor-phase may play an important rôle in the preliminary concentration of the metallics. If a difference in temperature and a difference in pressure can be established then the volatile constituents of the magmatic materials can escape; they will very likely be acid even though the igneous body is alkaline or neutral. These emanations can carry upward large amounts of metallic constituents and can profoundly alter the rock materials which they penetrate. This type of concentration will at first be independent of the concentration of the metallic sulfides or oxides from the alkaline or neutral magmatic fluids; subsequently, however, the two types of concentration are likely to merge gradually into one another.

In a paper about to be published, the concentration of the metallic constituents in the Valley of Ten Thousand Smokes will be described in detail.

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THE PRESENT STATUS OF SANTORINI

H. S. WASHINGTON

Contrary to the expectations that naturally followed from the history of the eruptions of 1707 and 1866, the present eruption of Santorini appears to be subsiding within two years of its beginning and to be reaching a fumarolic stage. It began beneath the sea in August 1925, and the center of eruption has subsequently shifted. Detailed data on the present stage of subsiding activity are not yet available.

RESEARCH WORK IN VOLCANOLOGY IN JAPAN

ARTHUR L. DAY

(This was an informal report, of which no abstract was prepared)

FACTORS BEARING ON THE FORMATION OF CRATERS ON THE MOON

F. E. WRIGHT

The craters and other surface features of the Moon have long attracted the attention of astronomers and geologists and many hypotheses have been suggested to account for their origin. Although a host of detailed observations have been made, we do not yet know definitely how any one of these features was formed, nor do we know definitely what the materials are that we see exposed on the Moon. The chief difficulty that confronts the geologist in his study of lunar physiography is the visualization of the conditions that obtain there; namely, lack of running water and of an atmosphere, and gravity only one-sixth that at the Earth's surface. Terrestrial features are so profoundly modified and altered by the action of water and of air that our whole geological experience is built up around these factors. The first task of the geologist who wishes to study the physiography of the Moon is to ascertain the physical environment of its surface materials and then to gather experience in the effects produced by such conditions. Erosion, weathering, and cementation in the ordinary terrestrial sense are inactive forces on the Moon's surface. Sedimentary rocks are apparently absent; they do not, as on the Earth, constitute the history-book of the Moon. In the absence of an atmosphere and of circulating water, geological history of the kind we know on the Earth cannot be recorded.

The lunar day is 29½ times as long as our day; the temperature range from midday to midnight is about 200°C. If water were on the Moon's surface, this temperature range would, in itself, mean disintegration of

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the rocks at a rapid rate. Because of the lack of an atmosphere, both fine dust and heavy blocks ejected into space above the Moon settle down to the Moon's surface with equal rapidity; there is no differential sorting of volcanic ash according to size. A blast of dust and ash-laden volcanic gas encounters no great resistance as in the case of a terrestrial explosion; once started, it will therefore tend to maintain its straight course better than on the Earth. This is no doubt one of the factors responsible for the long streaks on the Moon that at full Moon appear to radiate from several different craters. Winds and wind-erosion are inactive agents on the Moon; volcanic blasts may accomplish something, but only now and then.

The geologist faced with these conditions has not much of a background of experience on which to build. The obvious course for him to take is to commence with the simple facts at hand and to ascertain by test and by computation the behavior of materials under lunar conditions of experiment. As an example of this method of approach let us consider the flight of materials hurled out from a volcano on the Moon as compared with similar materials ejected by a terrestrial volcano.

A long series of computations on the flight of projectiles on the Moon ejected under different angles and with different muzzle-velocities shows that the ranges attained on the Moon are from twenty-five to fifty-fold those attained on the Earth for the same muzzle-velocities. The shape

TABLE 1—*Ranges of projectiles (angle of ejection = 50° or angle of departure = 40°) for different muzzle-velocities from 300 to 1000 meters per second on the Moon and on the Earth with and without an atmosphere and for the ballistic coefficients C = 1, 2, and 3*

Initial velocity meters per second	Meters / Feet	300 984.3	400 1312.3	500 1640.4	600 1968.5	700 2296.6	800 2624.7	900 2952.8	1000 3280.8
Moon.....	Km	55.8	100.6	160.2	236.2	330.8	446.5	586.8	755.8
	Miles	34.7	62.5	99.5	146.8	205.5	277.4	364.6	469.6
Earth without atmosphere...	Km	9.2	16.6	26.5	39.0	54.6	73.7	96.9	124.8
	Miles	5.7	10.3	16.5	24.2	33.9	45.8	60.2	77.5
Earth with atmosphere:									
$C=1$.....	Km	4.8	5.8	6.6	7.3	8.0	8.5	9.2	9.9
	Miles	3.0	3.6	4.1	4.5	5.0	5.3	5.7	6.2
$C=2$.....	Km	6.3	8.2	9.4	10.5	11.7	12.7	13.7	14.8
	Miles	3.9	5.1	5.8	6.5	7.3	7.9	8.5	9.2
$C=3$.....	Km	6.9	9.4	11.2	12.8	14.4	16.1	17.7	19.4
	Miles	4.3	5.8	7.0	8.0	8.9	10.0	11.0	12.1

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and density of the projectile on the Moon are not factors to be taken into account as is the case in exterior ballastics on the Earth. In Table 1 are listed the ranges of projectiles on the Moon for an angle of ejection $\beta = 50°$ for different muzzle-velocities from 300 meters to 1,000 meters per second; for comparison the corresponding ranges on the Earth without an atmosphere, and for the Earth with its atmosphere, and for projectiles with ballistic coefficients, $C = 1$, 2, and 3, are given. This table shows clearly the ranges that may be obtained on the Moon in comparison with those actually attained on the Earth. For example, an artillerist on the Earth firing a 75-millimeter gun may attain a range of five to eight miles; on the Moon his ranges for the same muzzle-velocities would be 230 to 280 miles. Were he to fire a Big Bertha, such as the Germans used against Paris during the war, with a muzzle-velocity of a mile a second, his range, instead of 72 miles on the Earth, would be 2,250 miles, or over one-fourth the distance around the Moon.

The significance of this extreme dispersion is realized when we consider a volcano in action on the Moon. Its materials are hurled into space with velocities like those on the Earth, but instead of falling back into the crater as on terrestrial craters they are flung far and wide. The crater-floor is left cleaned out down to the molten lava, if lava be there. It is characteristic of lunar craters that their floors are in general relatively flat, often with a central spire or peak, and that the level of the floor is below that of the surrounding plains. This factor of great dispersion must be adequately considered in any discussion of the Moon's surface-features. Under these conditions we should expect to find large craters greatly exceeding terrestrial craters in size, and this we do find. Lunar craters range in size from 800 miles maximum diameter to a minimum of less than one mile; in fact down to the limit of resolving power of the telescope. Lunar crater-rims rise above the surrounding plains to a height of 4,000 feet or more; the depth from the rim to the crater-floor may be 5,000 to 10,000 feet or more; the height of the central hill may be 1,000 to 5,000 feet. The largest terrestrial crater is less than 30 miles in diameter. According to Gilbert, the average diameter of the ten largest lunar craters is 275 miles (442 km); that of the ten largest terrestrial craters is eleven miles (18 km). Large lunar craters range from 8,000 to 15,000 feet (2,400 to 4,600 meters) in depth; terrestrial from 2,000 to 4,000 feet (600 to 1,200 meters). The floor of the lunar crater is commonly below the level of the surrounding plain; that of terrestrial craters is commonly well above the level of the adjacent plains.

With these relations in mind, let us consider the two theories of the formation of lunar craters that have aroused the most discussion; namely,

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the volcanic and the meteor-impact theories. Objection to the volcanic theory has been made because lunar craters do not resemble terrestrial craters in detail. I submit that under the conditions that obtain on the Moon, one cannot expect much similarity between lunar and terrestrial craters. The criteria for testing the theory of volcanic origin of lunar craters have not yet been established.

On the other hand, it has been asserted as a strong argument against the meteor-impact hypothesis that the craters are almost uniformly circular in outline, whereas one should expect elliptical shapes to be developed by meteors striking the surface at low angles. In the first place, it is not certain that this is mechanically necessary; in the second, when we realize that meteors strike the Moon at full speed without retardation by an atmosphere as on the Earth, a situation arises that needs investigation. The meteor projectile traveling, say, ten to twenty kilometers per second on impact penetrates some distance into the Moon's crust, sets up an aureole of intense compression which rebounds elastically and ejects some material. Moreover, by the abrupt stopping of the meteor its kinetic energy of translation is available both for mechanical deformation and for conversion into heat sufficient to melt the meteor itself and the adjacent rocks, to set free occluded gases and even to volatilize some of the material, thus producing an explosion analogous to a volcano in its action. In case the meteor were to penetrate deeply to a molten layer of rock a real volcano would result. In either case the original shape of the crater would be much changed by the action of the forces set up by the impact. The circular shape of the craters on the Moon, therefore, may not be construed as an argument against the meteor-impact hypothesis. More data are required before a definite decision can be arrived at regarding the mode of origin of these craters, to say nothing of other perplexing features on the Moon.

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VOLCANO STATIONS OF THE U. S. GEOLOGICAL SURVEY

W. C. MENDENHALL

On July 1, 1924, Congress transferred the Hawaiian Volcano Observatory, with its staff and equipment, from the Weather Bureau in the Department of Agriculture, to the Geological Survey in the Department of the Interior. This transfer brought to the Survey a going scientific concern. Since 1911, Dr. T. A. Jaggar, Jr., in charge of this observatory, at first under the auspices of the Massachusetts Institute of Tech-

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nology and later under the Weather Bureau, with the aid of local support in the Hawaiian Islands, has been engaged in a study of the volcanological problems exhibited at Kilauea. Throughout this period systematic records have been made of all the phenomena of volcanism that have been observed. Seismographs have been installed and records of tremors accumulated for systematic study; fluctuations of lava-levels in the pit of Halemaumau, the overflows from this pit and from the rifts in adjacent regions, including the outbursts along the slopes of Mauna Loa, have been studied. The composition of lavas and their gases have been made the particular subject of a joint research between the Observatory and the Geophysical Laboratory of the Carnegie Institution of Washington; variations in land-level, including tilt of the land toward and from the volcanic centers, have been recorded. Systematic reports on all of the observed phenomena have been published locally [1] and summaries of them are in course of publication in more permanent form.

On July 1, 1926, the Federal appropriations available for this type of work were increased and corresponding extensions of the work are now under way. Precise level-lines have been run by the U. S. Coast and Geodetic Survey, under a cooperative arrangement, from sea-level at Hilo to the summit of Mauna Loa. The local lines about Kilauea are tied to this base-line, so that both relative and absolute changes of level can now be detected; and by repeating the line to Mauna Loa in the future any changes in its elevation will be revealed. A large number of shallow borings are being made over the floor of the pit of Kilauea. These will be used to measure temperature-variations and temperature-distributions beneath the surface of the recent flows which cover this floor.

In the fall of 1926 an observatory was installed at Mineral, California, near the base of Mt. Lassen. Records are now being secured at this station in consonance with the general plan worked out at Kilauea. In the spring of 1927, Doctor Jaggar went to Alaska, where he will first install a station at Kodiak, convenient to Katmai Volcano and Augustine Island. It is expected that another station will be established later on Akutan Island between Shishaldin and Bogoslof. Seismographs, built at the Hawaiian Observatory, will be installed at these stations and local observers will be secured to keep them in continuous operation.

[1] See especially the Monthly Bulletin of the Hawaiian Volcano Observatory, and The Volcano Letter, a weekly news-leaflet of the Hawaiian Volcano Research Association.

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The developments from the Alaskan stations are not yet determined. The field is one exhibiting more active volcanological phenomena than any field on the mainland of the United States and, with continued support, an expansion of the observations from the seismologic records, with which the work will be started, to the broader field of volcanology in general will doubtless be undertaken.

U. S. Geological Survey,
Washington, D. C.

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SPECIAL REPORTS

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NOTE ON ACTIVITIES IN ATMOSPHERIC-ELECTRIC INVESTIGATIONS[1]

W. F. G. SWANN

The only matters needing report in connection with my activities in atmospheric electricity are briefly noted in the following paragraphs.

(1) I have developed a theory which is explained in its title as follows: A Modification of the Electromagnetic Equations consistent with restricted relativity and providing a possible explanation of the origin of the Earth's electric charge, of the Earth's magnetic field, and of gravitation. This paper was published in abstract form towards the end of my paper on "The Earth's Electric and Magnetic Phenomena," in the Journal of the Franklin Institute for February, 1926. It is now in process of publication in extended form in the Philosophical Magazine. It will also appear in the publication of the papers presented at the International Mathematical Congress in Toronto a couple of years ago.

(2) I have completed in Norway an investigation concerning a search for a possible corpuscular radiation of cosmic origin and the result is contained in the following sentence: Experiments indicate that the absolute magnitude of a current absorbed by a copper cylinder 20.6 cm in diameter and 19.3 cm high is no more than 1.5 per cent of that which would have been obtained by the complete absorption of a vertical corpuscular-current of densities sufficient to account for the replenishment of the Earth's charge.

(3) I have completed an investigation on the measurement of residual ionization in air with pressure up to 1,000 pounds per square inch, measurements having been carried out at the summit of Pike's Peak, Colorado Springs, and at New Haven. The results of this investigation will shortly be published.

(4) Extending number (1) to the magnetic field of sunspots it appears that peripheral velocities of the order of 80 kilometers per second are capable of giving rise to magnetic fields of the order of 2,000 gauss. Moreover, the indications are that Jupiter should have a very large magnetic field, a field of the order of 60,000 gauss.

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[1] Abstract-report prepared at the request of the Union for the Prague Assembly of the International Geodetic and Geophysical Union.

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REPORT UPON THE ORGANIZATION OF THE DEPARTMENT OF GEOPHYSICS AT THE COLORADO SCHOOL OF MINES, GOLDEN, COLORADO[1]

C. A. Heiland

In 1922, geophysical methods were used for the first time in the United States as an aid to detect mineral deposits, especially oil-bearing structures, which could not be found by geological investigations alone. The first instrument employed for that purpose was the Eoetvoes torsion balance; shortly after, seismic investigations were started, and recently magnetic and electric methods have been taken up. Thus far, the mining industry has used geophysical methods comparatively little. Magnetometers have been applied sometimes in search for iron ores in our northern states; for other ore deposits the electrical methods have been employed; extensively, however, only in Canada.

Geophysical measurements for such practical purposes as outlined above have been made in this country by private corporations exclusively. Consulting engineers, as well as companies, have done contracting work with one or more geophysical methods, or the large operating oil concerns have organized their own geophysical staffs. An idea of the amount of geophysical work as done at present may be obtained perhaps by conceiving that at present about five consulting engineers and about twelve companies are making geophysical measurements on the contract basis and that, on the other hand, about one hundred torsion balances, twenty seismographs, and fifty magnetometers are in use by the geophysical staffs of oil companies.

The development of applied geophysics in this country as characterized above has given rise to two serious problems. The first is the need of men who are trained equally well in the theory and the operation of geophysical instruments. The second is the need of a central and impartial place where researches on problems of applied geophysics are done and made public. In view of the fact that the essential features of most geophysical methods are kept secret yet, and that every company which starts this kind of work has, usually, to go back to the very beginning, the need for scientific public research for the benefit of the industry is obvious in order that time shall not be wasted in useless experimenting.

In consideration of these needs, the President of the Colorado School of Mines, Dr. M. F. Coolbaugh, decided in 1926 to establish a Department of Geophysics at the school. The organization of this Department,

[1] Report prepared at the request of the Union for the Prague Assembly of the International Geodetic and Geophysical Union.

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which began in January, 1927, was entrusted to the writer. The establishment of such a department, the first of its character in this country, at a mining school also aims to encourage the mining industry to apply the methods in question more than it has done before.

The program, which has been outlined for this work, consists of two parts, (1) the educational program, and (2) the research program.

We feel that a sufficient ability to handle any applied geophysical method intelligently cannot be attained by any person without a good foundation in general geophysics. Therefore a course in general geophysics is given at the school which is open to seniors and postgraduate students, and required for members of the special courses which concern theory and operation of instruments. From the next academic year on, the general course will be given in two semesters and will cover the following subjects: (1) The history of the Earth (cosmogonical hypotheses, paleogeography, paleoclimatology); (2) constitution and dynamics of the atmosphere (meteorology, atmospheric electricity, propagation of sound, etc.); (3) constitution and dynamics of the hydrosphere (hydrology, oceanography, tides); (4) the constitution and dynamics of the lithosphere (density, gravity, isotasy, earth-magnetism, chemical and physical constitution of the interior of the earth, radio-activity, earth-electricity, movement of the earth in space, bodily tides, volcanism, earthquakes, etc.). Because of its importance in applied geophysics, more emphasis is placed upon item (4) than upon items (1) to (3).

The operation of any geophysical instrument is confined to the special courses which are open for postgraduates only. In these courses, first in general the theory of the respective instruments is taught in detail, then some work is done in the laboratory, and finally the instruments are taken out to obtain practical field work. In the first semester, after the organization of the department, a special course in the theory and operation of the torsion balance was given. In the next semester, the theory and operation of magnetic variometers will be taken up. After that, a seismological course probably will follow; a course in electrical methods is also planned for the future. At present the school has a photographic recording torsion-balance and two magnetic field-balances for the horizontal and vertical intensity. In order to present the magnetometer course as well as is desirable, the recording of magnetic variations is indispensable; therefore, the very next thing planned is the erection of a magnetic observatory where three components—probably D, H, and Z—are to be recorded continuously. By the erection of a continuously recording magnetic observatory we also hope to contribute to the advancement of theoretical investigations, which are made in regard to the relationship of terrestrial magnetism and earth-electricity

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to atmospheric electricity and activity of the Sun, especially in this country by the well-known Department of Terrestrial Magnetism of the Carnegie Institution of Washington and the Division of Terrestrial Magnetism and Seismology of the U. S. Coast and Geodetic Survey.

The purchase, or construction, of a seismograph will also be a necessity sooner or later. We are also contemplating having our own precision-mechanics workshop on the campus in the very near future, in order to make all necessary instrument work as inexpensive as possible.

As far as the activities in the new department, aside from the educational program, are concerned, we felt that the first requirement for all studies in applied geophysics would be a thorough knowledge of the respective literature; however, at present, this is comparatively difficult to obtain because, first of all, a textbook on applied or general geophysics is not available yet in this country; secondly, because the literature on applied geophysics is scattered in journals of very different character. We have decided, therefore, to compile all articles—on applied geophysics as well as on general geophysics, the study of which is important for applied geophysics—which have been published, especially recently, in all countries of the world. This "Bibliography on Applied Geophysics" will be published as soon as possible.

The research work planned for the future in the department is, naturally, stipulated by the equipment which we have at present. As far as the torsion balance is concerned, it is our aim to make this method, which so far has been applied to the greatest extent to oil propositions, also practical for use in mining by practical and theoretical investigations. Our research work pertaining to magnetic methods is to start with investigations about the physical, especially thermic, properties of their fundamental constituents—the magnets. The generosity of one of the leading manufacturers of geophysical instruments has enabled us to start these and the ensuing investigations. The school has been presented with three apparatuses especially designed for these purposes. Extensive researches are also planned on the magnetization of rocks, in view of the fact that that is one of the most complex phenomena, and it seems to be worth while, especially from the physico-chemical standpoint, to investigate the conditions under which an induced and a permanent magnetization of rocks is originated.

Colorado School of Mines,
Golden, Colorado.

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GEOPHYSICAL EXHIBIT

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GEOPHYSICAL EXHIBIT

(Washington, D. C., April 22 to 29, 1927)

GENERAL DESCRIPTION

An exhibit of geophysical instruments, researches, and applications was displayed from 9 A. M. to 5 P. M. during Friday, April 22, through Friday, April 29, 1927 (except Sunday, April 24), in the southwest and northeast exhibit-rooms of the building of the National Academy of Sciences and National Research Council, Washington, D. C.

The exhibits, arranged for largely by the executive committees of the different sections, were furnished by the following institutions and individuals: American Petroleum Institute; Roald Amundsen and H. U. Sverdrup, *Maud* Expeditions of 1918-1925; Astrophysical Observatory of the Smithsonian Institution; Blue Hill Meteorological Observatory; Bureau of Standards; Carnegie Institution of Washington, through its Department of Terrestrial Magnetism, Geophyscial Laboratory, and Mount Wilson Observatory; Coast and Geodetic Survey; Georgetown University; L. Gorczynski; T. A. Jaggar, Jr., for the Volcano Observatory, Hawaii; National Geographic Society; Naval Observatory; G. W. Pickard; Scripps Institution of Oceanography; Smithsonian Institution; University of Michigan Expedition to Greenland, 1926; Weather Bureau; Weston Electrical Instrument Corporation. The appreciative thanks of the Union are due to these organizations and individuals for their cooperation and interest which contributed so largely to the success of the exhibit and of the meetings.

The exhibits were classified under subject-headings corresponding to the fields of activity of the different sections and are briefly described below.

GEODESY

(*a*) Invar-pendulum apparatus for measuring the intensity of gravity.

(*b*) Geodetic level and level-rod used in extending precise level-lines.

(*c*) Tape stretcher and invar tape used in accurate measurements of distances.

(*d*) Type of theodolite designed and constructed by the Coast and Geodetic Survey used on most of the precise triangulations in the United States since 1897. (This theodolite has twelve-inch circle, five-minute graduations, and is read by each of three micrometer-microscopes to one second of arc.)

(*e*) Personal-equation apparatus for measuring personal equation of observers in astronomical observations.

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SEISMOLOGY

(*a*) Earliest type of Milne seismograph for photographic recording of distant earthquakes, originally installed by Milne in 1899 at Oahu College, Honolulu.

(*b*) The Wood-Anderson torsion-seismograph, devised recently by H. O. Wood and J. A. Anderson under the auspices of the Carnegie Institution of Washington for recording nearby or distant earthquakes.

(*c*) Typical earthquake-records (seismograms) obtained by Milne and by Wood-Anderson seismographs.

(*d*) Photographs of various types of seismographs and earthquake-effects, and diagrams showing transmission of earthquake-waves.

(*e*) Photographs, paintings, instruments, and models showing development of the seismograph:

(1) First seismograph after Choko, A. D. 136.
(2) A painting of the ancient dragon-frog seismoscope.
(3) De Haute Feuille seismoscope, A. D. 1703 (first improvement on Choko's machine).
(4) A simple mantle-type tromometer to show slight earth-tremors.
(5) One of the early seismographs constructed on modern principles.
(6) A model of the famous "Sekiya's wires" showing the actual path of an earth-particle during an earthquake.
(7) Vertical seismograph of Galitzin operated at Georgetown.

(*f*) Seismograms recorded by great earthquakes:

(1) Japan, September 1, 1923, record at Tokyo.
(2) Sumatra, June 28, 1926, record of vertical seismograph at Georgetown.
(3) Saguenay Basin, Canada, February 28, 1925, record at Georgetown and showing possible cause of misinterpretation.
(4) Heavy microseismic disturbance recorded at Georgetown.

METEOROLOGY

(*a*) The Marvin copper-cone pyrheliometer for measuring solar radiation. (The cone with small angular opening has interior surface specularly reflecting, thus insuring nearly complete absorption.)

(*b*) Smithsonian silver-disk pyrheliometer. (The bent tube mercurial thermometer, with bulb imbedded in the silver disk, measures temperature-changes in the latter as it is alternately exposed to and shielded from radiation.)

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(*c*) Gorczynski's type of solarimeter. (A Moll thermopile with a Weston microammeter for measuring the current generated by the radiation absorbed at the thermal junctions.)

(*d*) McAdie's multiple-scale thermometer. (A mercurial thermometer provided with six adjustable scales for direct readings of (A) temperature by (1) Fahrenheit scale, (2) Centigrade scale, (3) absolute scale, (4) kilograd scale, and of (B) water-vapor showing (1) saturation density and (2) pressure.)

(*e*) Fergusson balloon-meteorograph. (Distinctive features are (1) a mechanism providing a two-part scale for more accurate reading of pressure, (2) a single time arc for all elements simplifying reading of records, and (3) light weight, permitting use of small, inexpensive balloons.)

(*f*) Photographs taken on 1926 Greenland Expedition of University of Michigan. (Aerological data and synoptic charts for Greenland and vicinity, August, 1926.)

(*g*) Series of seven graphs showing Sun and weather variations.

(*h*) Slide-rule extrapolator. (A special arrangement of six slide-rules on one mounting to facilitate the computation of solar radiation-observations; the time of reduction is reduced nearly five-fold by this extrapolator.)

TERRESTRIAL MAGNETISM AND ELECTRICITY

(*a*) Shaw fading recorder for taking graphic records of radio-signal fluctuations.

(*b*) Temperature-compensated variometer with diagrams showing increased efficiency through such compensation in magnetic-observatory work and compilations.

(*c*) Scaling device for reading photographic records directly in absolute units.

(*d*) Transparencies from photographs in the Arctic Sea off the North Coast of Siberia, 1918 to 1925, showing types of aurora.

(*e*) Transparencies of correlations between solar activity and (1) the magnetic and electric activities of the Earth, (2) radio reception.

(*f*) Earth inductor and galvanometer for detailed study of anomalies and geological formations.

(*g*) Apparatus for observing radio signal-intensities at magnetic and electric observatories.

OCEANOGRAPHY

(*a*) Portable automatic tide-gauge to record tides for reduction of soundings to datum (reference) plane in hydrographic surveys.

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(*b*) Pressure sounding-tube to determine depths down to 100 fathoms.

(*c*) Allen-type water-bottle, five-liter capacity, to secure water-samples for quantitative study of plankton and other microscopic forms of sea life.

(*d*) Improved bottom-samplers of the Davis, and Eckman and Albatross types to secure samples of mud and ooze from the bottom of the ocean.

(*e*) Tentative route planned for Cruise VII of the *Carnegie* from 1928 to 1931, during which oceanographic, as well as magnetic and electric, investigations will be undertaken.

(*f*) Graphs for solving the equation for calculation of surface-currents from temperature-data and for determining density or salinity.

(*g*) Graphs showing sub-surface distribution of diatoms.

VOLCANOLOGY

Photographs of volcanoes, hot springs, and lunar craters, as follows:

(*a*) Aso Volcano, Kyushu Island, Japan, 1927. (The original caldera-type crater is 60 miles in circumference, and is said to be the largest in the world; the present mountain mass arises from the center of this caldera to a height of about 5,000 feet and contains five active craters.)

(*b*) The Kilauea (Halemaumau crater, Hawaii, in 1917 when nearly filled with lava.

(*c*) "Valley of Ten Thousand Smokes" near Mt. Katmai, Alaska, National Geographic Society's expedition of 1917.

(*d*) Lava lake at Kilauea showing the islands frequently formed by the separation of great sections of the surrounding basin.

(*e*) Hot springs of the "Porcelain Basin," Yellowstone National Park.

(*f*) Craters of the Moon photographed at Mount Wilson Observatory, September 15, 1919:

(1) Northern portion of Moon at last quarter.

(2) Southern portion of Moon at last quarter.

(3) Region about Crater Copernicus at last quarter.

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GENERAL

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to July 1, 1927)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; and (f) Volcanology.

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The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of three years, and not to be eligible for immediate re-election to their respective offices; and a general secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose eligibility and periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the general secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the American officers of the International Geodetic and Geophysical Union, and of its Sections, the chairman of each of the Standing Committees of the American Geophysical Union, and the chairman of each of the following Divisions of the National Research Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

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ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairman-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five members shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

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ALPHABETICAL ADDRESS LIST OF MEMBERS OF THE AMERICAN GEOPHYSICAL UNION[1]

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[1] Total number of members on July 1, 1927, is 72. The letters following each name indicate the sections with which the member is affiliated, these being (*a*) Geodesy, (*b*) Seismology, (*c*) Meteorology, (*d*) Terrestrial Magnetism and Electricity, (*e*) Oceanography, and (*f*) Volcanology.

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EX OFFICIO MEMBERS

The Chairman, Division of Foreign Relations, National Research Council.
The Chairman, Division of Physical Sciences, National Research Council.
The Chairman, Division of Chemistry and Chemical Technology, National Research Council.
The Chairman, Division of Geology and Geography, National Research Council.
The Chairman, Division of Biology and Agriculture, National Research Council.

OFFICERS OF THE UNION

Chairman, H. S. Washington (1926-1929)
Vice-Chairman, G. W. Littlehales (1926-1929)
General Secretary, J. A. Fleming (1925-1928)

OFFICERS OF SECTIONS

Section	Chairman	Vice-Chairman	Secretary
Geodesy	William Bowie (1926-1929)	F. E. Wright (1926-1929)	W. D. Lambert (1925-1928)
Seismology	L. H. Adams (1926-1929)	N. H. Heck (1926-1929)	D. L. Hazard (1925-1928)
Meteorology	H. H. Kimball (1926-1929)	G. W. Littlehales (1926-1929)	A. J. Henry (1926-1929)
Terrestrial Magnetism and Electricity	N. H. Heck (1926-1929)	J. H. Dellinger (1926-1929)	J. A. Fleming (1926-1929)
Oceanography	T. W. Vaughan (1926-1929)	G. T. Rude (1926-1929)	Austin H. Clark (1926-1929)
Volcanology	T. A. Jaggar, Jr. (1926-1929)	F. E. Wright (1926-1929)	R. B. Sosman (1925-1928)

MEMBERSHIP OF SECTIONS[1]

Section (a) Geodesy (number of members, 23)

Louis A. Bauer
William Bowie, Chairman (1926-1929)
L. J. Briggs
E. W. Brown
R. L. Faris
George E. Hale
D. L. Hazard
L. M. Hoskins
Lewis V. Judson
W. D. Lambert, Secretary (1925-1928)
A. O. Leuschner
G. W. Littlehales
J. B. Macelwane
A. A. Michelson
F. R. Moulton
H. F. Reid
Frank Schlesinger
W. F. G. Swann
S. D. Townley
C. E. Van Orstrand
H. S. Washington
H. O. Wood
F. E. Wright, Vice-Chairman (1926-1929)

[1] The affiliations with sections of the ex officio members are not shown in these lists, owing to inevitable changes from year to year.

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SECTION (b) SEISMOLOGY (number of members, 83)

L. H. Adams, Chairman (1926-1929)
J. A. Anderson
Louis A. Bauer
N. L. Bowen
William Bowie
E. W. Brown
R. A. Daly
A. L. Day
R. L. Faris
J. A. Fleming
D. L. Hazard, Secretary (1925-1928)
N. H. Heck, Vice-Chairman (1926-1929)
L. M. Hoskins
W. J. Humphreys
T. A. Jaggar, Jr.
Lewis V. Judson
W. D. Lambert
A. C. Lawson
A. O. Leuschner
A. G. McAdie
J. B. Macelwane
C. F. Marvin
A. A. Michelson
H. F. Reid
G. T. Rude
Francis A. Tondorf
S. D. Townley
C. E. Van Orstrand
T. Wayland Vaughan
H. S. Washington
Bailey Willis
H. O. Wood
F. L. Wright

SECTION (c) METEOROLOGY (number of members, 27)

C. G. Abbot
J. P. Ault
W. D. Bancroft
Louis A. Bauer
W. R. Blair
E. H. Bowie
H. H. Clayton
J. A. Fleming
O. H. Gish
W. R. Gregg
George E. Hale
A. J. Henry, Secretary (1926-1929)
W. J. Humphreys
H. H. Kimball, Chairman (1926-1929)
G. W. Littlehales, Vice-Chairman (1926-1929)
A. G. McAdie
J. B. Macelwane
C. F. Marvin
S. J. Mauchly
R. A. Millikan
F. R. Moulton
G. P. Paine
W. E. Parker
G. T. Rude
W. F. G. Swann
R. DeC. Ward
Bailey Willis

SECTION (d) TERRESTRIAL MAGNETISM AND ELECTRICITY (number of members, 25)

C. G. Abbot
J. P. Ault
L. W. Austin
S. J. Barnett
Louis A. Bauer
W. R. Blair
J. H. Dellinger, Vice-Chairman (1926-1929)
R. L. Faris
J. A. Fleming, Secretary (1926-1929)
O. H. Gish
W. R. Gregg
George E. Hale
D. L. Hazard
N. H. Heck, Chairman (1926-1929)
A. J. Henry

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W. J. Humphreys
G. W. Littlehales
A. G. McAdie
J. B. Macelwane
C. F. Marvin
S. J. Mauchly
R. A. Millikan
W. E. Parker
W. J. Peters
W. F. G. Swann

SECTION (e) OCEANOGRAPHY (number of members, 31)

J. P. Ault
H. B. Bigelow
William Bowie
L. J. Briggs
A. H. Clark, Secretary (1926-1929)
F. W. Clarke
R. A. Daly
W. M. Davis
R. L. Faris
J. A. Fleming
Harvey C. Hayes
N. H. Heck
A. J. Henry
W. D. Lambert
G. W. Littlehales
A. G. McAdie
G. F. McEwen
H. A. Marmer
S. J. Mauchly
A. A. Michelson
H. F. Moore
F. R. Moulton
Robert C. Murphy
W. E. Parker
W. J. Peters
H. F. Reid
G. T. Rude, Vice-Chairman (1926-1929)
C. E. Van Orstrand
T. Wayland Vaughan, Chairman (1926-1929)
Roger C. Wells
Bailey Willis

SECTION (f) VOLCANOLOGY (number of members, 24)

L. H. Adams
N. L. Bowen
William Bowie
L. J. Briggs
E. W. Brown
F. W. Clarke
Whitman Cross
R. A. Daly
A. L. Day
W. J. Humphreys
T. A. Jaggar, Jr., Chairman (1926-1929)
J. B. Macelwane
C. F. Marvin
S. J. Mauchly
F. A. Perret
H. F. Reid
R. B. Sosman, Secretary (1925-1928)
George Steiger
C. E. Van Orstrand
H. S. Washington
Roger C. Wells
Bailey Willis
H. O. Wood
F. E. Wright, Vice-Chairman (1926-1929)

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OFFICERS SINCE ORGANIZATION

OFFICERS OF THE AMERICAN GEOPHYSICAL UNION[1]

Chairman	Vice-Chairman	General Secretary
William Bowie, 1920-22	Louis A. Bauer, 1920-22	H. O. Wood, 1919-21
Louis A. Bauer, 1922-24	Arthur L. Day, 1922-24	W. J. Humphreys, 1921-22
H. F. Reid, 1924-26	H. S. Washington, 1924-26	William Bowie, 1922-25
H. S. Washington, 1926-29	*G. W. Littlehales*, 1926-29	*J. A. Fleming*, 1925-28

OFFICERS OF THE SECTIONS[1]

Section	Chairman	Vice-Chairman	Secretary
(a) Geodesy	William Bowie, 1920-22 J. F. Hayford, 1922-24 R. L. Faris, 1924-26 *William Bowie*, 1926-29	J. F. Hayford, 1920-22 R. L. Faris, 1922-24 J. F. Hayford, 1924-25 William Bowie, 1925-26 *F. E. Wright*, 1926-29	H. O. Wood, 1920-22 William Bowie, 1922-25 *W. D. Lambert*, 1925-28
(b) Seismology	H. F. Reid, 1920-22 W. J. Humphreys, 1922-24 J. B. Woodworth, 1924-26 *L. H. Adams*, 1926-29	J. C. Branner, 1920-22 J. B. Woodworth, 1922-24 L. H. Adams, 1924-26 *N. H. Heck*, 1926-29	H. O. Wood, 1920-22 *D. L. Hazard*, 1922-28
(c) Meteorology	C. F. Marvin, 1920-22 E. H. Bowie, 1922-24 C. G. Abbot, 1924-26 *H. H. Kimball*, 1926-29	W. J. Humphreys, 1920-22 R. DeC. Ward, 1922-24 H. H. Kimball, 1924-26 *G. W. Littlehales*, 1926-29	*A. J. Henry*, 1920-29
(d) Terrestrial Magnetism and Electricity	Louis A. Bauer, 1920-22 W. F. G. Swann, 1922-24 Louis A. Bauer, 1924-26 *N. H. Heck*, 1926-29	W. F. G. Swann, 1920-22 Louis A. Bauer, 1922-24 N. H. Heck, 1924-26 *J. H. Dellinger*, 1926-29	*J. A. Fleming*, 1920-29
(e) Oceanography	G. W. Littlehales, 1920-22 J. P. Ault, 1922-24 N. H. Heck, 1924-26 *T. W. Vaughan*, 1926-29	A. G. Mayor, 1920-22 G. W. Littlehales, 1922-24 W. J. Peters, 1924-26 *G. T. Rude*, 1926-29	J. T. Watkins, 1920 W. E. Parker, 1920-23 G. T. Rude, 1923-26 *A. H. Clark*, 1926-29
(f) Volcanology	H. S. Washington, 1920-22 L. H. Adams, 1922-24 *T. A. Jaggar, Jr.*, 1924-29	R. A. Daly, 1920-22 T. A. Jaggar, Jr., 1922-24 N. L. Bowen, 1924-26 *F. E. Wright*, 1926-29	H. O. Wood, 1920-21 *R. B. Sosman*, 1921-29
(g) Geophysical Chemistry[2]	Arthur L. Day, 1920-22 H. S. Washington, 1922-24	F. W. Clarke, 1920-22 Whitman Cross, 1922-24	R. B. Sosman, 1920-24

DATES OF ANNUAL MEETINGS OF UNION AND OF ITS SECTIONS

First, April 23, 1920
Second, April 18-20, 1921
Third, March 6, 8, 1922
Fourth, April 17-19, 1923
Fifth, May 1-3, 1924
Sixth, April 30, May 1, 1925
Seventh, April 29, 30, 1926
Eighth, April 28, 29, 1927

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[1] The names of the officers for the eighth annual meeting are indicated by italics.
[2] Discontinued May 31, 1924, as International Union failed to provide for such a Section.

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DECEASED MEMBERS

J. C. Branner, died March 1, 1922
A. G. Mayor, died June 24, 1922
R. S. Woodward, died June 29, 1924
J. F. Hayford, died March 10, 1925
J. B. Woodworth, died August 5, 1925

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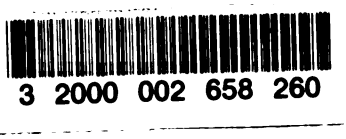
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